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DYNAMO-ELECTRIC MACHINES

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DYNAMO-ELECTRIC MACHINES

AND

CENTRAL STATION EQUIPMENT

A Complete Practical Exposition of the Principles Governing the
Construction and Action of Dynamo-Electric Generators,
Electric Motors, Transformers and all other Station
Equipment. Prepared especially for the
use of Engineers, Electricians and all
Students of Electrical Engineering.

BY

CALVIN FRANKLIN SWINGLE, M.E.

The Installation, Care and Operation of Dynamos, Motors, Transformers, Rotary Converters, Electro-Metres, The Construction and Management of Switch Boards, Lightning Arresters for the Station and Line, Current Distribution, Electric Currents, Direct and Alternating, Arc Lamps, Incandescent Lamps, Primary and Storage Batteries, all treated upon at length and clear explanations given, accompanied by numerous Illustrations.

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INTRODUCTION

The practical study of electrical engineering is subject to the same inexorable law that governs the realm of nature, viz: "the survival of the fittest," and satisfactory progress can only be made when the student is given an opportunity to prosecute his studies along lines in conformity with the aforesaid law.

Such an opportunity is herewith presented. The tendency in the development of electrical engineering has, during the past twenty years, been towards simplification rather than complication. Many of the older devices and theories have been discarded as worse than useless, and modern thought, and inventive genius have succeeded in establishing the science upon the solid foundation of practicability where it is bound to remain. With these facts in view an earnest effort has been made in the compilation of the following treatise to outline a course of study which shall be in close conformity with modern practice.

A short study of the nature of electricity, and magnetism is presented at the beginning of the book. The magnetic circuit, and electro-magnetic induction are clearly explained, also the action of lines of force surrounding an active conductor, a careful study of which, together with the numerous illustrations will enable the student to grasp the fundamental principles of the dynamo-electric generator, which subject immediately follows. In treating of the dynamo a special effort has been made in the direction of thoroughness, as well as simplicity, and, as the easiest way to comprehend the principles of the dynamo is to follow up its construction from the most simple type to one of the more complicated forms, this plan has been strictly adhered to, the student being led by easy steps through the various stages of dynamo construction, all being clearly explained and profusely illustrated. The care and operation of dynamo-electric generators is dwelt upon at length, instructions and rules being given for the guidance of those in charge.

From the dynamo to the electric motor is but a step, therefore the subject of motors is next taken up, and freely discussed. Electric currents, direct, and alternating, current phase, waves, &c., each and all receive due attention. Switches, and switch boards, including oil switches, being parts of the equipment in which engineers and electricians in charge of central stations are vitally interested, a large space has been devoted to a description of their installation and management, the same being made clear by diagrams and illustrations. Transformers and rotary converters are dealt with in a manner at once plain and thorough, the principles controlling their action being clearly explained, and reliable instructions given concerning their care and management.

A large space is also devoted to the interesting subject of the construction and action of the various types of electro-metres, also their installation and management.

Current distribution, arc and incandescent lamps, the operation of the three wire system, lightning arresters for the station, and for the line, are each and all clearly explained and illustrated. Numerous wiring tables are also given for the use of linemen and others. A complete catechism of questions and answers bearing upon the different subjects immediately follows the close of each section, and as this is one of the many valuable features of the work, much care and thought has been bestowed upon it to make it reliable. Primary and storage batteries, their construction and action are also explained in detail, together with instructions for their care and management.

Dynamo—Electric Machines

Electricity is an invisible agent, the exact nature of which is not very well known, although the laws governing its action, the methods of controlling it, and the effects produced by it are becoming well known. It is necessary to assume in the start that it is of such a nature as to be susceptible of possessing quantity. We may, and do use terms to designate definite and definable quantities of electricity without being able to say just what is meant by the word itself. For instance, referring to an electric current, it is the transfer of definite quantities of electricity along a conductor, just as in a current of water, gallons, or cubic feet are transferred through a pipe. But, the idea of large quantities of electricity being stored up in receptacles for future use, in a similar manner to water, cannot be followed except in a limited sense, as for instance, in the case of storage batteries. One of the most, if not the most important generalizations ever made in physical science is the doctrine of the conservation of energy, or as it is sometimes called, the doctrine of the indestructibility of energy. This doctrine teaches that the total quantity of the energy in the universe is unalterable; that is, if energy is expended or disappears in one form, it must reappear in another form. A simple analogy will serve to make this matter plain: Suppose a man, by means of a rope passing over a pulley, raises a 100-pound weight one foot above the surface of the earth, which means 100 foot pounds of work, or energy. Now, the man has exerted, or put forth that amount of energy, and so far as he is concerned, he no longer possesses it. Apparently it has been blotted out of existence—annihilated. But this annihilation is only apparent for the reason that energy is capable of existing in two forms, viz., kinetic, and potential or stored energy. While the muscular force of the man is being expended in actually doing work raising the 100-pound weight, it is in a condition called kinetic energy. While the weight is held in position at a distance of one foot above the earth, it is producing a stress, or pull on the rope, and is in the condition of stored or potential energy. If the rope is suddenly loosed, the weight will descend, and during this descent will put forth an amount of kinetic energy exactly equal to the 100 pounds of work or energy that was expended in raising it one foot from the ground.

Much of the mystery that exists in the minds of many persons concerning electricity will be unraveled and made clear when it is understood that, like all other natural forces, electricity is only one of the many forms in which energy manifests itself. Like all other forms of energy, electric energy, or the power that electricity possesses of doing work, is fixed and determinate.

An electric source, whether it be a voltaic cell, or a dynamo, is capable, under given conditions, of producing a certain quantity of electricity. In the case of the dynamo being operated by the steam-engine, the heat energy stored in the fuel by the sun's rays, is made to do a certain amount of work, through the medium of the boiler, the steam, and the engine, and this work or energy is simply changed by the dynamo into the form of electric energy, and passes on out through the circuit to do useful work in the way of power, lighting, etc.

When electricity is caused to flow between any two points in a circuit, the amount of work it can perform is equal to the amount of electricity that passes, multiplied by what is called the difference of potential through which the electricity falls or moves.

When work is done on a quantity of water by forcing it into a reservoir at a higher level than that from which the water has been raised, the amount of work done can be measured in foot-pounds by the quantity of water in pounds so raised, multiplied by the difference in level through which it is raised in feet. While it is not the intention to suggest that electricity is a fluid, yet it possesses many of the properties of a fluid, so that the amount of work electricity is capable of doing depends on the quantity of electricity moved, as well as on the difference of the electric level or potential through which it has been raised.

The unit of quantity of a water current may be taken as a cubic foot or a cubic inch. In electricity the practical unit of quantity is a certain quantity of electricity called a coulomb. In measuring this quantity of electricity, reference must be had to certain other electrical units, i. e., the ampere, the volt and the ohm.

The ampere is the name given to a practical unit of electric current, and is such a rate of electric flow as is capable of transmitting a quantity of electricity equal to one coulomb per second. A current of electricity equal to one ampere will flow through a circuit whose resistance is one ohm, when acted on by an electromotive force or pressure of one volt. An ampere is approximately such a current of electricity that is capable of depositing 1.118 milligrammes of silver per second from a specially prepared solution of silver nitrate.

The volt or practical unit of electromotive force is an electromotive force or pressure that is capable of causing the flow of an electric current of one ampere through a circuit, the electric resistance of which is equal to one ohm.

The ohm is the practical unit of electric resistance. It is the resistance that would limit the flow of electricity under an electromotive force of one volt to a current of one ampere, or to a discharge of one coulomb per second. It is equal to the resistance of a column of pure mercury one square millimetre in area of cross section and 104.9 centimetres in length.

A coulomb is the practical unit of electric quantity. It is the quantity of electricity that would pass in one second through a circuit carrying a current of one ampere.

Electric energy can be measured in terms of electric power or rate of doing work. A careful distinction should be made between work, or the product of force by the distance through which the force acts, and power or rate of doing work. As we have already seen, the unit of work is called the foot-pound. The unit of power or rate of doing work, or, as it is sometimes called, the unit of activity is equal to the foot-pound per second, or foot-pound second.

The amount of work electricity is capable of doing is equal to the quantity of electricity that flows, multiplied by the difference of level or potential through which it flows. This is the volt-coulomb or joule. The amount of electric activity or work per second is equal to the volt-ampere or the watt.

THE WATT.

The volt-ampere or watt is equal to the power developed when 44.25 foot-pounds of work are done per minute, or 0.7375 foot-pounds per second.

If the ampere is replaced by the symbol C, the volt by the symbol E, the watt by the symbol W, and resistance by R, then, $C \times E = W$, and $C^2 \times R = W$.

The square of the current multiplied by the resistance equals watts; and the square of the voltage divided by the resistance equals watts, thus: $E^2 \div R = W$, expressed in figures as follows:

First. An electromotive force or pressure of 10 volts and a current of 20 amperes equals,

$$10 \times 20 = 200 \text{ watts.}$$

Second. A current of 10 amperes and a resistance of 30 ohms equals,

$$10 \times 10 \times 30 = 3000 \text{ watts}$$

Third. An electromotive force of 10 volts, and a resistance of 20 ohms equals,

$$10 \times 10 \div 20 = 5 \text{ watts}$$

MAGNETS.

The *natural* magnet is a mineral consisting of a combination of iron and oxygen, and its composition is indicated by the chemical formula $Fe_3 O_4$. The mineral is called magnetite, and it is attracted by the magnet just as iron is, only not so powerfully.

Some samples of magnetite attract iron. These are natural magnets known to the ancients as the lodestone.

The *permanent* magnet is a piece of steel which has been charged with magnetism, and retains it. It attracts iron, its ends having the strongest attractive power, it tends to point north and south, the same end always tending towards the same pole. The poles of the magnet are thus determined, and are designated the north pole, and the south pole.

The north poles of two magnets tend to repel each other, and the south poles influence each other in the same manner. But the north pole of one magnet attracts the south pole of another; like repels like, and unlike attracts unlike.

There are various methods of charging magnets. One process is as follows: Lay a bar of steel on a table, and with one pole of a permanent magnet, stroke the steel bar from center to end, always lifting the magnet clear of the bar on the return stroke. This is repeated a number of times, and then the same operation is applied with the other pole of the magnet to the other half of the bar. The end of the bar stroked with the north pole of the magnet will be a south pole, and vice versa. The stroking may be done for both halves of the steel bar by using two magnets at the same time. The north pole of one magnet and the south pole of the other are brought almost together at the center of the bar, and simultaneously moved out to the ends, always lifting them clear of the bar on the return stroke, and the stroking is repeated.

The U-shaped Magnet, or as it is usually called, the horseshoe magnet, may be charged or magnetized by stroking with another horseshoe magnet from near the bend to the ends, or from the ends to the bend. A piece of iron should be laid across the ends during the process.

The Electro-Magnet.—If a bar of iron be surrounded by a coil of wire through which an electric current is passing, it will become charged magnetically, and will attract iron.

LINES OF FORCE.

The passing of a current of electricity produces a condition of more or less strain, or whirl in the ether, and unless distorted in some way the locus or locality of the condition is symmetrical with respect to the current. This locality is called the field of force. It affects iron, and is traced, and may be located by its effects upon the needle of the compass, or upon iron filings. It is by virtue of the field of force that every dynamo electric generator, and every electric motor works. A needle held near a magnet is attracted because of the field of force. In the case of the mariner's compass, the needle is influenced by the earth's field of force. A coil of wire rotated within any artificial field of force, will generate electromotive force, and it is due to this principle that the revolving armature of a dynamo, or more properly speaking, a generator, produces currents and potential capable of doing work of various kinds. We can thus see that the electric current in its effects is a very real and tangible thing, although in theory it is somewhat imaginary. The magnet is the most familiar producer of lines of force, and the polarity, or direction of these lines is fixed by assuming that they pass through the steel of the magnet from its south pole to its north pole, and issuing from the latter, curve around through space and return to the south pole. The direction taken by the electric current is fixed by assuming that when produced by a galvanic battery, it starts from the copper electrode, and passes through the outer conductor, to the zinc plate, and the lines of force

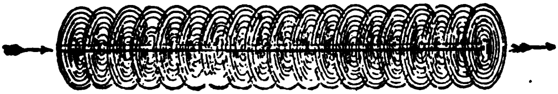

FIG. 421

LINES OF FORCE SURROUNDING AN ACTIVE CONDUCTOR surrounding the conductor will be in planes at right angles to it, and will form closed lines around it. These lines may be circular or otherwise, and their polarity, or in other words, their direction of rotation, may be expressed by saying that it is opposed to the motion of the hands of a watch or clock, assuming that the current is coming toward a person, and corresponds to the motion of the clock hands when going away from the person. In the first case, the polarity is anti-clockwise, and in the second case, it is clockwise. Figs. 421 and 422 will serve to illustrate the principle governing the action of these lines, the arrows in Fig. 421 indicating the direction of the current, while Fig. 422 may be called an "end view."

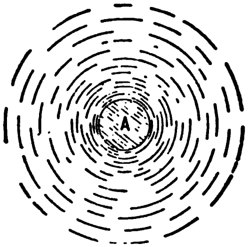

FIG. 422

LINES OF FORCE SURROUNDING AN ACTIVE CONDUCTOR

The smoke rings often produced from the smoker's pipe are good representations of the whirling motion of these lines of force. A conductor that is swept through a field of force in such a direction as to cut the lines of force, has electromotive force impressed upon it, and if the ends of the conductor are connected so as to form a closed circuit, a current of electricity will pass through it. The electric current may therefore be considered as electricity in motion, and the line of force with absolutely fixed direction may be assumed to have a whirling motion around its axis, which latter does not change, see Figs. 421 and 422.

When a current passes through a spiral conductor, as shown in Fig. 423, in the direction indicated by the small arrows, the direction of the lines of force produced will be as indicated by the large arrow; but if, instead of passing through the spiral conductor, the current should pass through a conductor occupying the position of the large arrow, then the lines of force would follow the direction of the small arrows.

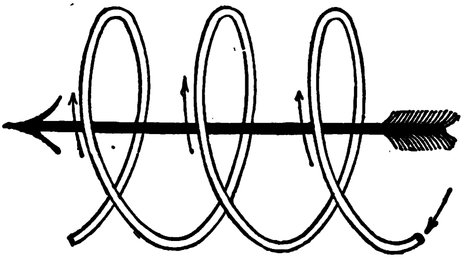

FIG. 423

DIRECTION OF LINES OF FORCE PRODUCED BY A CIRCULAR CURRENT

There are, then, surrounding a conductor carrying a current of electricity, an infinite number of lines constituting in fact a volume of force, and the strength of this volume, or field, varies with its nearness to, or distance from the conductor.

In practice, the field near the conductor is the only portion strong enough to play any part in useful work, and this strength or density is estimated by the relative number of lines of force in a given cross-sectional area of the field.

THE MAGNETIC CIRCUIT.

A fundamental difference exists between the electric, and the magnetic circuit. By a constant electric current passing upon its circuit, energy is developed, and energy must be expended to maintain it; but the lines of force are maintained in their circuit without the expenditure of energy. The entire course taken by lines of force must be a closed curve, either a circle, or an ellipse. In the field of force maintained by the horseshoe magnet, or other shaped magnets, the lines of force pass through the magnet, and also through the space surrounding it, and their path may approximate a circle, or an ellipse, or be a combination of lines and curves, but this path must be continuous. A straight line of force, or a line of force extending into space without limit, is impossible. For the passage of an electric current, a conductor forming a closed circuit is required. This conductor may be any form of matter, although a distinction is to be made between good and bad conductors. For the passage of the magnetic circuit or lines of force no such arbitrary requirement exists, although a distinction is also to be made, as, for instance, air, or a vacuum are the worst conductors, while iron is the best. There is in fact very little difference in substances as regards their ability to pass lines of force, with the exception of iron which has over three hundred times the power of passing lines of force that air has. The electric current passes through a conductor in intensity proportional to the electromotive force urging it. The magnetic circuit passes through air or a vacuum in proportion to the magneto-motive force urging it.

In order to create new lines of force, or in other words to build up a field of force, new energy must be expended;

but when the field of force is once built up, no energy is required to maintain it, as the full current passing through the circuit unopposed, except by resistance, maintains the field of force without the expenditure of energy. This condition is similar to the carrying of a weight up a flight of stairs. Energy is expended in carrying the weight to the top of the stairs, but when there it is maintained there without requiring the expenditure of energy, and the energy exerted in bringing the weight up-stairs would seem to have disappeared, or to have been annihilated. But this is not the case. On the contrary, the energy is stored in the weight, and will be again expended when the weight is taken down. So also the energy expended in building up a field of force is stored there in the form of electric potential, and may be expended in the production of kinetic electric energy when the field goes out of existence. This disappearance of the field occurs when the electric current ceases, the lines of force disappearing at a more or less rapid rate, and in doing so they develop forward electromotive force of the same polarity as the original current, thus forcing additional current through the line.

The leading characteristics of the field of force may be summed up under the following general headings:

First. Energy is expended in building up a field of force.

Second. No energy is expended in the maintenance of a field of force.

Third. Energy is expended in the destruction of a field of force.

Fourth. A field of force, then, must be, and is the location of potential energy.

Electro-Magnetic Induction.—If we take a coil of wire, Fig. 424, and rapidly thrust a magnet into it, we shall observe a certain deflection of the galvanometer needle shown with it. This deflection continues only while the magnet is in motion. After we have inserted the magnet and it has come to rest the galvanometer needle will return to its normal position. When we withdraw the magnet the deflection of the needle will be in the opposite direction. If the magnet is inserted or withdrawn with a very quick motion, the deflection will be considerable. If the magnet is very slowly inserted, or withdrawn the deflection will hardly be noticeable. The same phenomena will occur if instead of moving the magnet, we hold it stationary and move the coil, or if both of them be moved towards or from each other. The deflection of the compass needle indicates that a current of electricity is passing along the wire, and the experiments above described show exactly how currents of electricity are produced in dynamos.

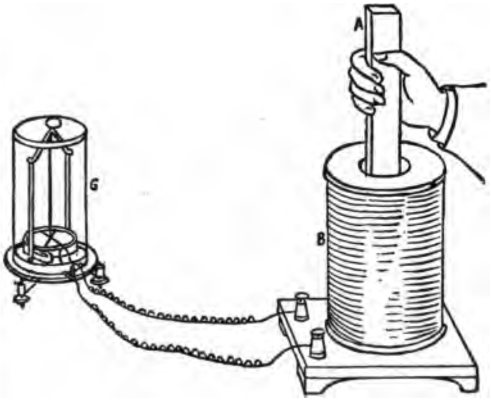

Fig. 424

While a natural magnet will maintain a field of force indefinitely without the expenditure of energy, it is necessary that energy be indirectly expended in maintaining the field of a dynamo, for the reason that an electro-magnet is preferred to a natural magnet in such a machine, because by its use the dynamo may be made much smaller and lighter.

An electro-motive force is induced by rapidly cutting lines of force, that is, by moving either a magnet over a wire or a wire over, or near a magnet. The current in turn is the result of this electro-motive force acting in a closed circuit. A bar of iron becomes an electro-magnet if we wind about it a few turns of wire and cause a current of electricity to flow along the wire, Fig. 425. The magnetism is conceived to consist of lines of force, which leave the bar at one end and enter it at the other, the direction of these lines depending upon the direction in which the current circulates about the bar of iron. The number of these lines of force depends upon the number of ampere turns in the iron bar and on the diameter, length, and quality of the iron bar.

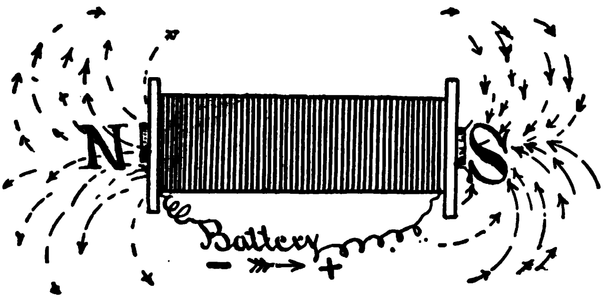

FIG. 425

The meaning of the word ampere as used in electric practice has already been defined.

Ampere turns is a term used to indicate the magnetizing force; it is the number of turns of wire on a magnet multiplied by the current in amperes flowing through these turns of wire.

Haskins, in *Electricity Made Simple,* explains it in this manner: "If, for instance, we have a current of one ampere flowing through a single turn of wire around a bar of soft iron, and we have developed enough magnetism to lift a keeper or other piece of iron, weighing one ounce, then with one-half the amount of current and two coils around the bar, we would obtain the same result, and with three turns of wire we would require but one-third the current to develop the same lifting power in the bar or magnet."

The law of magnetic flow is very much the same as the law of current flow. If the iron bar is of low magnetic resistance, the flow will be quite great; if of high resistance, the flow will be small.

Lines of force can also be shunted just as a current of electricity can; that is, they will follow the path of lowest resistance just as a stream of water or a current of electricity will.

Faraday's law of induction is as follows: "When a conductor is moved in a magnetic field so as to cut the lines of force, there is an electro-motive force impressed on the conductor in a direction at right angles to the direction of the motion, and at right angles also to the direction of the lines of force."

Foucault or Eddy Currents.—If a conductor should be so moved in a magnetic field that the number of lines of force passing through it at an angle with its direction of motion vary, a current will be produced within it. This current will circle, or eddy around within the conductor, and will absorb energy, and expend it in heating the metallic body of the conductor. These local currents are called Foucault or eddy currents, and are a hindrance, rather than a help to the generation of useful currents.

DYNAMO-ELECTRIC GENERATORS.

The dynamo is a machine for transforming mechanical energy into electrical energy—mechanical energy is required to operate the mechanism for changing field and armature relations, and this energy is absorbed by the dynamo, and electric energy is produced in its stead. The easiest way to comprehend the principles of the dynamo is to follow up its construction from the most simple type, to one of the more complicated forms. Dynamos are classified into two grand divisions, viz., alternating (A. C.) dynamos, and direct current (D. C.) dynamos. The A. C.

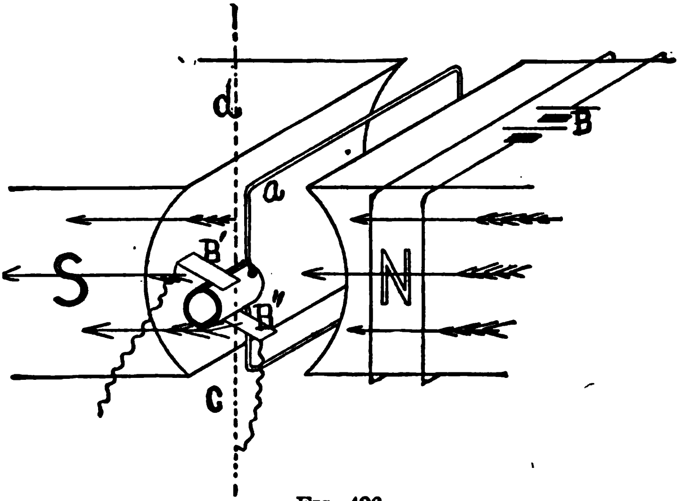

Fig. 426

dynamo produces a current that reverses its direction of flow periodically, in practice from twenty times and upward per second. The D. C. dynamo produces a current of unchanging direction.

The principal constituent parts of a dynamo are the armature, consisting of a core and windings, the field consisting also of core and windings, the collecting rings, or commutator, and brushes. The armature and field vary in construction, their windings vary in system, and from these variations, many different varieties of dynamos are constructed.

Fig. 426 is an elementary sketch of a D. C. dynamo.

The wire a represents the armature, and we have also the iron bar, and the coil of wire wound on it and, for the present, we may consider the battery B as the source of the current which produces the magnetism or lines of force in the iron bar. The battery current magnetizes the iron bar (which in dynamos is known as the field magnet) and produces the lines of force indicated by arrows.

These lines of force leave the field magnet of the dynamo at the north pole marked N, and pass through the air-gap, and armature into the south pole marked S. As we begin to move the wire or armature, it cuts through these lines of force and begins to generate an electro-motive force, which in turn will cause the current to flow if the circuit is closed through a lamp or other device.

This current reverses in direction as the wire *a* passes from the influence of the south pole into that of the north pole, and the brushes B′ and B″, which transmit the current to the outside wires, are so set that they change the connection of the wire *a* at the time that it passes from one pole to the other. By this means the current in the external circuit is kept constant in direction, although it alternates in the armature.

The faster we turn the wire or armature, the greater will be the electro-motive force generated. Instead of using only one wire, as in Fig. 426, we may take many turns before bringing the end out, and in so doing obtain the well known drum armature, or, by a slightly different method of winding, the gramme ring armature, Fig. 427.

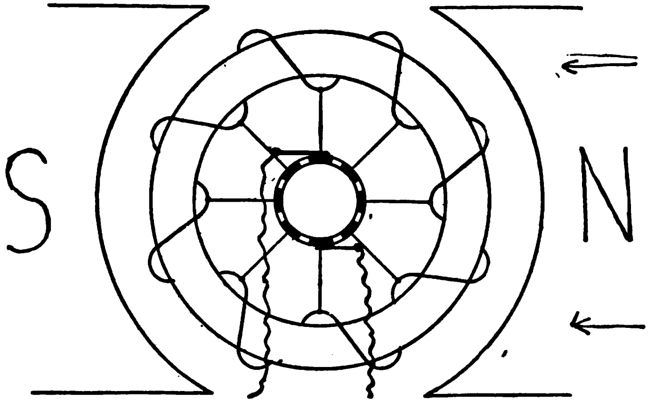

FIG. 427

Here we have many wires cutting the lines of force at once and the electro-motive force with the same number of revolutions of the armature is correspondingly increased, and the more turns of wire we arrange to cut those lines of force per second the greater will be the E. M. F. Instead of providing more wire or increasing the speed of the armature we can increase the magnetism, or number of lines of force, by sending more current through the fields, that is increasing the ampere turns.

If we wish to reverse the current flow we can do so by revolving the armature in the opposite direction, or by reversing the current through the fields.

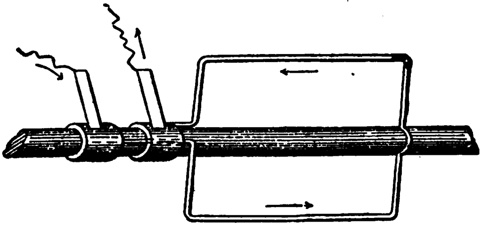

FIG. 428

USE OF COLLECTING OR SLIP RINGS

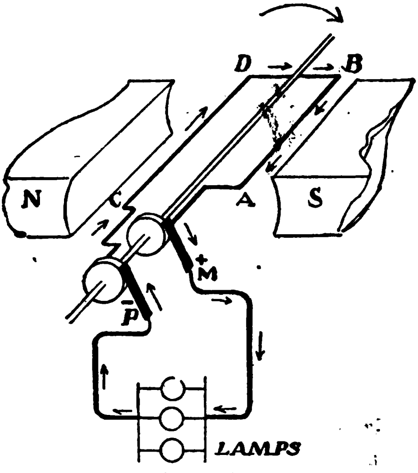

FIG. 429

THE SIMPLE ALTERNATING CURRENT DYNAMO. BRUSH M IS POSITIVE

Elementary Idea of an Alternating Current Dynamo.—If instead of the brushes B′ and B″ as shown in Fig. 426, we collect and transmit the current to the outside circuit by means of collector rings as shown in Fig. 428, we will then have an alternating, instead of a direct, or constant current as before mentioned.

In Figs. 429 and 430 are shown two positions of the loop on the armature of an alternator. The collector rings are insulated from the shaft and each other by mica. The terminals of the loop are soldered or riveted (sometimes both) to the rings, and current is led to the external circuit containing the lamps by stationary strips of copper which form a sliding contact with the rings.

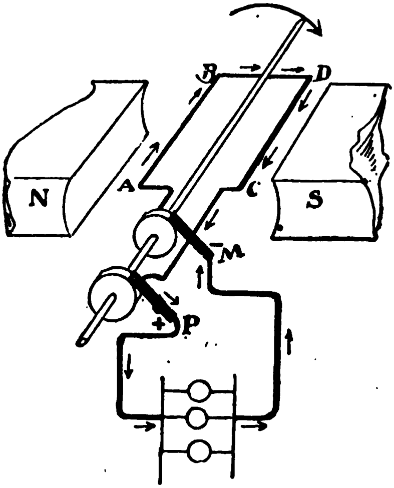

Fig. 430

THE SIMPLE ALTERNATOR, SHOWS COIL AT ONE-HALF A REVOLUTION FROM FIG. 429. BRUSH M IS NOW NEGATIVE

Referring to Fig. 429 it will be seen that during the first half of the revolution of the loop ABCD, the direction of the electro-motive force in AB is from B to A, and in CD is from C to D.

The current flows from the brush M to the lamps so that M is positive.

Reference to Fig. 430 shows that the wire in front of the S-pole is still positive, but that it is now the wire CD instead of AB, so P is the positive brush for the second half of the revolution. There are two reversals of the current per revolution.

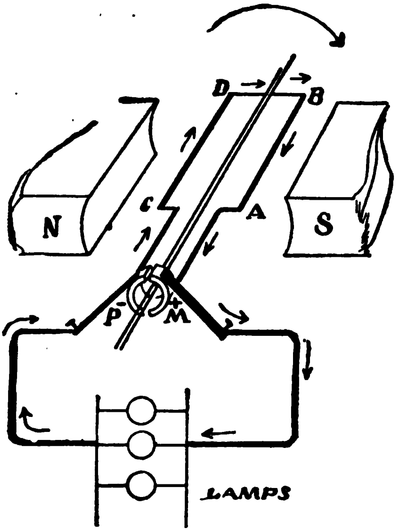

FIG. 431

SIMPLE D. C. GENERATOR. AT THIS INSTANT THE BRUSH M IS POSITIVE

The number of *alternations per minute* is the speed in revolutions per minute multiplied by the number of poles. The number of cycles is found by multiplying the speed in revolutions per second by the number of pairs of poles. The number of cycles is usually spoken of as the *frequency* of the alternator.

The usual frequencies are for power 25, for motor circuits, and arc lamps 66, and for incandescent lighting 133.

The Direct Current Generator.—In Fig. 431 is shown a loop and a two part commutator of a direct current generator.

Since the wire AB is moving down past a S-pole, the current flows from B to A and out of the brush M, which is called the positive brush. In wire CD the current flows from C to D, making P the negative brush.

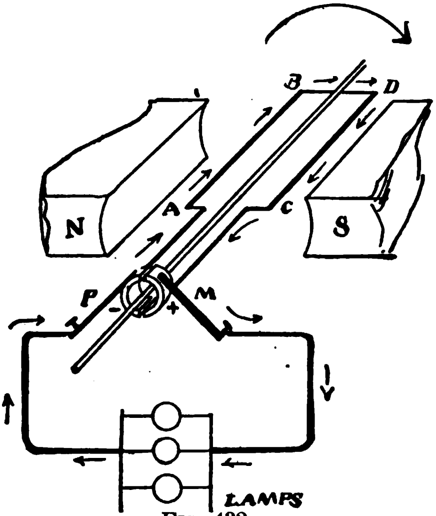

FIG. 432

SIMPLE D. C. GENERATOR. THE ARMATURE HAS MADE HALF A REVOLUTION, BUT BRUSH M IS STILL POSITIVE

After half a revolution the wire CD is over where AB was, and is now delivering the current towards the external circuit instead of away from it; *but CD is now connected through its commutator bar to brush M instead of to P so that the brush M is still positive.* (See Fig. 432.)

This arrangement of commutator bars and brushes performs the duty of connecting the brush M to that part of the winding, and only that part which is moving down in front of a S-pole. As long as the wire AB moves up in front of a N-pole the commutator connects it to brush P, but as soon as it moves down in front of a S-pole it is immediately disconnected from P, and a connection made with M.

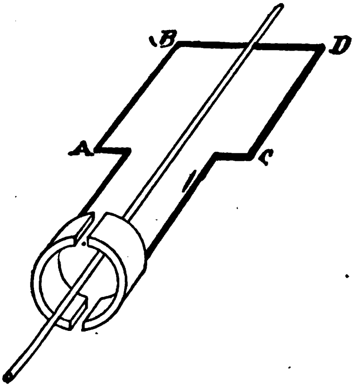

FIG. 433

AN ARMATURE COIL CONNECTED TO A TWO-PART COMMUTATOR, SO AS TO DELIVER DIRECT CURRENT

The two brushes are placed as shown in Fig. 434. In this case the alternating electro-motive force will be reversed or commuted at the proper instant, and there will be a one direction electro-motive force impressed on the outside circuit. The split ring is called a commutator, and is formed of alternate sections of conducting and non-conducting material, running parallel with the shaft with which it turns. It is placed on the shaft of the armature so that it rotates with it, as shown in Fig. 437. The brushes press upon its surface and collect the current from the bars. (See Fig. 438.) The function of the commutator as before stated, is to change the connections of the armature coils from the + or positive to the negative or — side of the circuit at the time at which the coil connected to the bar under the brush passes from the influence of one pole piece into that of the other. This is the time at which the current in the coil reverses in direction, and is called the neutral point. If we consider, for the sake of simplicity, an armature having only one turn of wire on it, as Fig. 426, there will be a time while the coil is in the position indicated by dotted lines at c and d when no current is being generated. The brushes on any dynamo should always be set at this point, for this is the point of least sparking. In actual practice all commutators have quite a number of bars and it is impossible to avoid, in passing under the brushes, that at least two of them are in contact with a brush at the same time. If a brush did leave one bar before it touches another, the current would be entirely broken for that length of time, and much sparking would result. The nature of all armature windings is such that while the brush is in contact with the commutator bars it short circuits that coil between them. This is the main reason why the brushes must be kept at a point at which the coil which is short circuited generates no current.

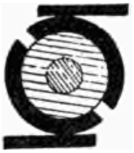

FIG. 434

CROSS SECTION OF SIMPLE COMMUTATOR. BLACK REPRESENTS COPPER; WHITE SPACE IS MICA INSULATION

Although the electro-motive force generated in one coil of a dynamo is very weak, the resistance of the "short circuit" formed by the dynamo brush is also very weak and therefore the current may be quite strong. This current is the main cause of sparking in dynamos. The number of bars constituting a commutator depends upon the winding of the armature, and the number of coils grouped thereon. By increasing the number of coils and commutator sections the tendency to spark at the brushes is decreased, and the fluctuations of the current are also decreased. However, there are many reasons against making the number of bars on a commutator very great. Increasing the number of bars in a commutator increases the cost of manufacture, and in smaller dynamos, if the number of bars be increased beyond a certain extent, each bar becomes so thin that a brush of the proper thickness to collect the current from the commutator would lap over too many bars of the commutator at one time. Each commutator bar should be of the size that will present sufficient metal for the carrying capacity of the current generated in the coil to which it is connected. Different builders of dynamos have different ideas as to the number of amperes that may be carried per

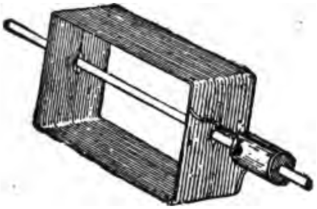

FIG. 435
A SINGLE COIL ARMATURE OF MANY TURNS

square inch in a commutator bar, but where a commutator is made of 95 per cent. copper it is usual to allow for each 100 amperes a commutator bar surface of 1½ sq. in.

The method of electrical connection between the commutator bar and the coil of the armature varies in different designs. Some builders solder the terminals of the coils to the commutator bars; others bolt the terminals of the coils to the bars; and some makers use hard drawn copper and "form" the armature coil in such a manner that both ends of the coil become commutator bars, making the coil continuous from one end of the commutator bar to the end of the diametrically opposite commutator bar.

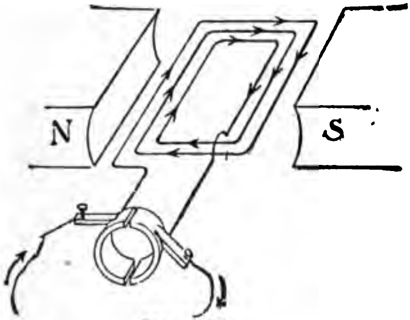

FIG. 436

AN ARMATURE COIL OF MANY TURNS SHOWING HOW THE INDUCED E. M. F. OF EACH TURN ADDS ITSELF TO THAT OF OTHER TURNS

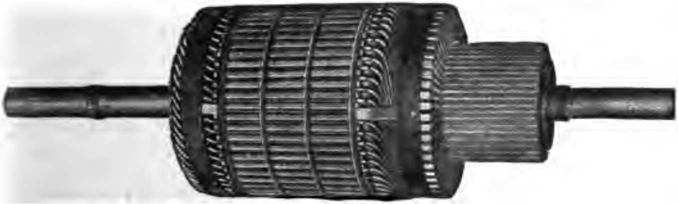

FIG. 437

To increase the electro-motive force. The greater the field strength, and the higher the speed the greater the electro-motive force.

When the speed has been raised until the surface of the armature is traveling at the rate of 3,000 ft. per minute* no further increase is made, lest the bursting stresses become too great.

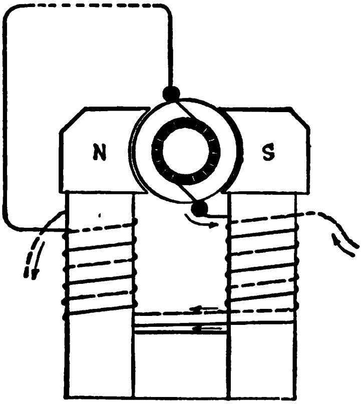

FIG. 438

SEPARATELY AND SELF-EXCITED SERIES DYNAMO.

In order to further increase the electro-motive force more *turns* or *loops* of wire must be wound on the armature. A coil of 16 turns as in Fig. 435 will give an electro-motive force 16 times as great as a coil like Fig. 426. Reference to Fig. 436 will serve to make this plain.

Suppose the direction of rotation to be the same as the hands of a watch when viewed from the commutator end of the machine; then the electro-motive forces induced in the successive portions of the wire will be as shown by the arrows, and will add to each other impressing a high electromotive force on the brushes. These turns of wire are said to be in series.

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*This is called the Peripheral Speed of the armature and is calculated by this rule:

P. S. equals 3.1416 x D x R. P. M. where D is the diameter of armature in feet and R. P. M. is the revolution of the armature per minute.

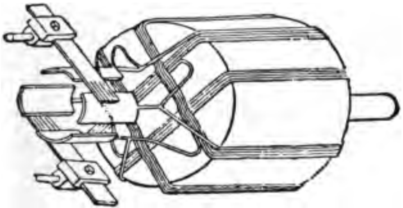

FIG. 439

DRUM WINDING ON A DRUM CORE. FOUR COILS AND FOUR COMMUTATOR BARS. FOR DIRECT CURRENT

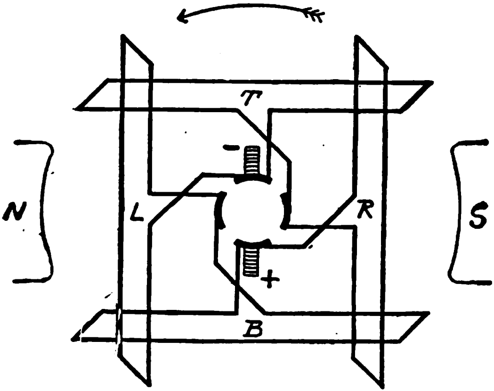

FIG. 440

DIAGRAM OF FIG. 439

Any betterment of the magnetic conductivity of the frame of the machine will increase the electro-motive force; by producing a greater flux per pound of copper on the field magnets. Hence the winding of the armature inductors (wires) on a core of very softest iron is an economic necessity, resulting in either a higher electro-motive force or a reduction of the expense for copper in the field coils.

These cores are called *Drum cores* when the central hole is just large enough for the shaft and the insulation around it (Fig. 439); and are named *Ring cores* when the internal diameter of the ring is much larger than the shaft. (Fig. 441.) The armature in Fig. 442 has a ring core, but the end plates being in position, the large hole is concealed.

These cores are built up of a great many punchings of soft iron from 15 to 40 mils thick, pickled so as to rust them a little. Every tenth one is varnished or tissue paper pasted on. The rust, varnish and paper are all insulators and when the punchings are assembled in a core, prevent *Eddy currents* from flowing from one end of the armature to the other and heating it.

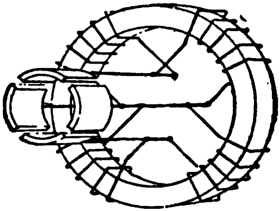

FIG. 441
SIMPLE GRAMME RING WINDING

These cores are sometimes *smooth,* but more frequently are *slotted* with the wires laid in the slots.

About 10 to 15% of the length of the core is insulation, and about 50% of the surface is slotted, containing the inductors (wires.)

Continuous Electro-Motive Force.—While a single coil of many turns produces a high electro-motive force, which by a two part commutator is always applied to the external circuit in the same direction, yet this coil passes through all the changes in voltage mentioned in connection with Fig. 426. Fig. 441 shows the construction of the Gramme ring, so named from the inventor, Gramme. The winding is on a ring coil made up of soft iron punchings 25 mils thick. The wires on the outer surface are active, having electro-motive force induced in them, and called armature inductors. Fig. 443 shows the same winding with eight coils, and eight commutator bars. In Fig. 442 the armature as diagramed in Fig. 443 is shown completed with its four bands. These bands are from 12 to 25 convolutions of phosphor-bronze wire in sizes varying from No. 20 up to 14, laid on tightly over a mica insulation and sweated with solder all the way round.

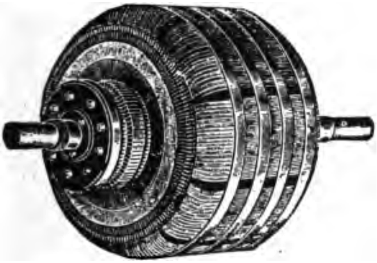

FIG. 442

EIGHT SECTION EIGHTY COIL RING WINDING ON A SMOOTH RING CORE, WITH EIGHTY BAR COMMUTATOR. FOR DIRECT CURRENT

Referring to 443 it will be seen that the complete winding can be divided into two parts, one influenced by the N-pole, the other by the S-pole standing at the commutator end. The N-pole side moving upwards has its electro-motive force in direction from back to front of armature *through the inductors*; the S-pole side has electro-motive force in direction from back to front of armature *through the dead wire.*

In winding the armature the wire is laid on in a continuous spiral as shown. This makes the electro-motive force in each half of the armature in series, and allows the current to flow from one coil to another, except at the points where the N-half and S-half of the armature meet. Here the electro-motive forces oppose and if wires were connected for an instant to the winding, as shown in the cut, the two opposing electro-motive forces would both force electricity out into the wire at the top of the armature, and draw it in at the bottom as shown by the arrows on these wires. This will cause a current to flow in the external circuit.

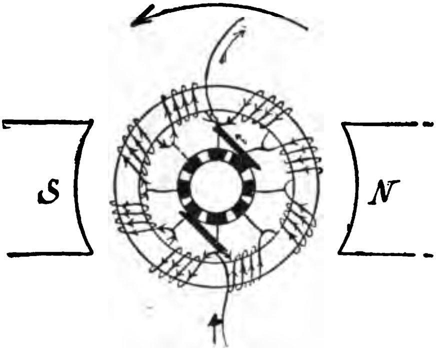

FIG. 443

EIGHT COIL GRAMME RING WINDING, WITH EIGHT PART COMMUTATOR

If the junctions of the coils are connected to eight commutator bars, (one bar per coil), and connect the ends of the external circuit by brushes to the commutator bars which are midway between the N- and S-poles, then each half of the armature separately generates an electro-motive force, and delivers current to the external circuit.

Suppose the armature to be revolving at the highest safe speed. Each inductor will move past the magnet poles at a speed of 3,000 feet a minute. With pole pieces 5 x 8 inches and a *flux density* of 90,000 lines per square inch, the *total flux* will be 5 x 8 x 90,000 or 3.6 million lines.

The armature may be 9 inches in diameter which gives it rotative speed 1,270 (nearly).

For R. P. M.[*]=P.S.[†]÷(3.1416×diameter).

$$=\frac{3000\times 12}{3.1416\times 9}=1270 \text{ nearly}$$

and R.P.S.[‡]=21 nearly.

An inductor therefore cuts 3.6 million lines of magnetism twenty-one times a second, which is equivalent to cutting 75.6 millions once per second.

Since the cutting of 100 million lines per second by an inductor induces 1 Volt pressure, each inductor on this armature revolving in this field will produce 75.6÷100 or ¾ of a volt approximately.

The 4 coils of 4 inductors each (Fig. 443) on the N-half of the armature being in series produce 3 volts per coil or a total of 12 volts *which is the electro-motive force of the generator.*

The S-half of the armature also generates a pressure of 12 volts, which is not added to the pressure of the N-half, being in parallel with it. An inspection of Fig. 443 shows that they oppose rather than add to each other; but an outlet being provided they turn aside through it, and send currents separately and independently towards the outside circuit.

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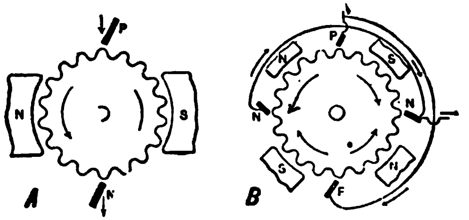
[*] Revolutions per minute.

[†] Peripheral speed.

[‡] Revolutions per second.

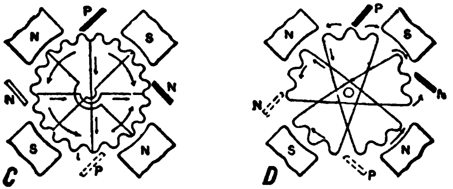
[§] American Wire Gauge.

If the armature is wound with No. 10 wire A.W.G.§ the diameter of which is 0.102 inch or 102 mils, its area is 102 squared equal to 10,404 c. m. Allowing 700 c. m. per ampere, it will carry 15 amperes, without too much heating.



Two Pole, Two Circuit

Four Pole, Four Circuit, Four Brushes in Multiple.



Four Pole, Four Circuit, Cross Connected Two Brushes or Four Brushes, in Multiple.

Four Pole, Two Circuit Ring Two Brushes or Four Brushes, in Multiple.

FIG. 444

SHOWING THE NUMBER AND POSITION OF BRUSHES ON DIFFERENT ARMATURE WINDINGS

The black brushes are the ones actually used, the dotted ones being dispensed with on account of the particular winding.

Since each side of the armature delivers its own current to the brushes, the safe current output of this generator is 30 amperes.

Suppose there are 250 ft. of this No. 10 wire on this armature. The resistance of the wire according to the wiring table is 1.02 ohms per 1,000 ft.

The resistance of *all the wire* on the armature is 0.255 ohm, and the resistance of the wire on each *half* of the armature is 0.128 ohm.

But the two halves are in parallel so *the resistance of* the armature as measured from brush to brush will be one-half of 0.128 or 0.064 ohm. The drop, or loss of pressure in the armature will be C x R or 30 x 0.064=1.92 or say 2 volts. This machine being a shunt generator, the main current does not pass through the fields, and there is no further voltage lost.

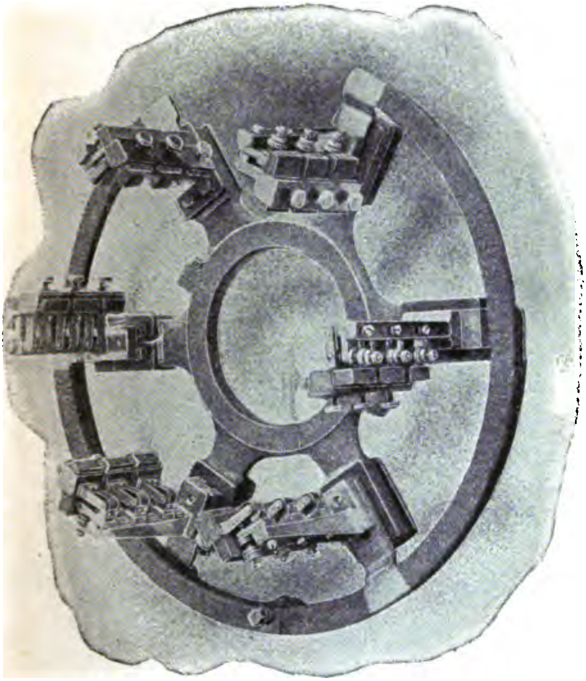


FIG. 445

The electro-motive force of this dynamo is 12 volts, and its voltage is 10 volts.

Its output in watts will be 10×30=300 watts or 0.3 K.W. This is the rating of the machine, and it will carry

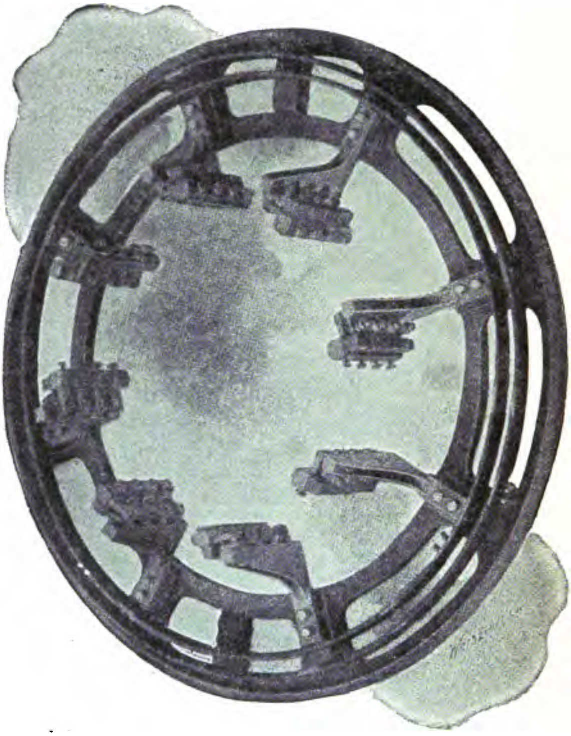


FIG. 446

this load 22 hours a day without getting more than 90° Fahr. hotter than the surrounding atmosphere. A properly proportioned machine will stand a 25 per cent overload for half an hour, rising an extra 30° in temperature, and it will stand a 50 per cent overload for one minute without being damaged by the heat.

Drum Winding.—The extra labor involved in passing the dead wire through the bore of a ring core is avoided by going back to first principles again, and placing on the core, (either drum or ring) a number of coils shaped as in Fig. 435, producing a winding as shown in Fig. 439. It is to be noted that the inductors lie entirely on the outer surface of the core, and that the percentage of dead wire is less than in Fig. 441. For a long, small diameter armature, drum winding uses the least wire, while for a short, large diameter core, the ring winding will require fewer pounds of copper. In order to make the diagram in Fig. 440 clear it has its proportions wrong. The dead part of the wire is drawn very long and the active part very short. The reverse is true of an actual winding.

Referring to Fig. 439, and using Fig. 440 as a guide, the left side of the armature is the N-pole side and the right the S-pole side; and the armature is revolving anticlockwise (otherwise the upper brush would be positive).

The electro-motive forces on the N-side and S-side of coil T, as in Fig. 436, are in series and add up, producing a current flow towards the lower (positive) brush. The current passes through the inactive (dead) coil R in order to get to the positive brush.

At the same time the electro-motive forces in coil B add up and passing through the dead coil L, drive current out of the lower brush.

The value of the electro-motive force is eight times that which one inductor can produce. For the active coil T has 4 loops, i. e., 8 inductors in series, as also has the coil B. Suppose T produces 8 volts, the two coils T and B are in parallel and do not add their electro-motive forces.

The coils L and R are dead, L being in series with B and R in series with T, but they produce no electro-motive force. At the present instant they are but a wasteful resistance; their value, however, will be soon seen.

When the armature has moved about 1/8 of a revolution, T is cutting flux slantingly and R, which is in series with it, is beginning to cut flux also. T is only 3/4 active, producing say 6 volts, and R is not totally dead but 1/4 active, producing 2 volts. Hence the voltage of the machine is still 8.

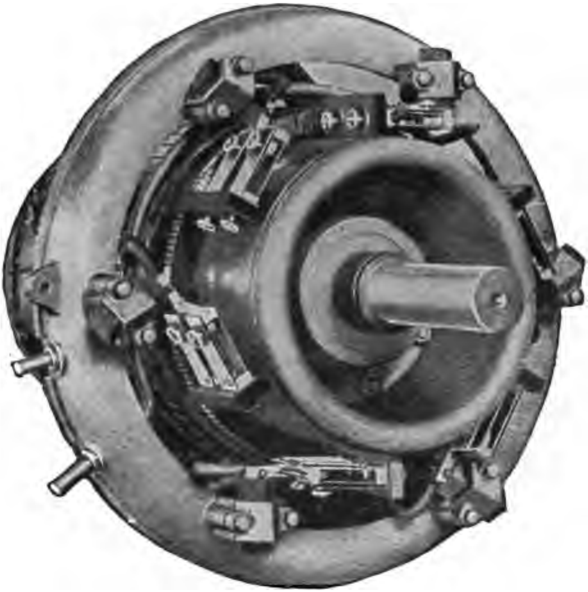


Fig. 447

At 1/4 revolution R is doing full work and B is dead and in series with it, while T is dead and L in series with it is at full activity. Now R and L produce the electro-motive force.

The current enters the armature through the upper brush, splits and passes through the armature by two parallel circuits, one containing T and R in series and the other containing L and B. During a revolution these coils interchange places, but two coils are always in each circuit.

When 6 amperes flow in the external circuit the No. 16 wire of the armature is not overheated, as it has but 3 amperes to carry. It has 2583 circular mils, which is more than 3×700 C. M.

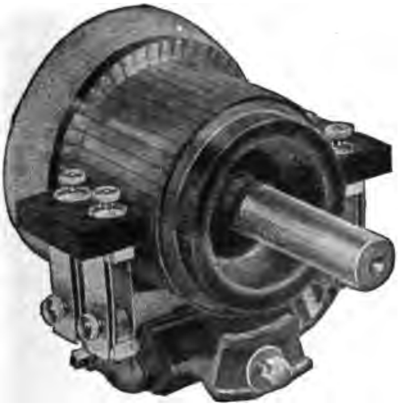


FIG. 448

Self-excitation of a Dynamo.—When a dynamo is standing idle the field magnets are weakly magnetic, due to residual magnetism.

Let the armature revolve, and in a shunt, or compound machine open, and in a series generator close the external circuit.

A few volts will be generated and cause a current to flow though the fields, hence the magnetism will increase and more voltage will be induced. This voltage will send increased current through the shunt field, and cause more volts to be induced.

The machine is now "building up."

As more and more magnetism is put into the fields, it becomes harder to get any more in as the iron is approaching *saturation* and there is more and more *leakage.*

Hence at a certain point, depending on the design of the machine, the difficulty of increasing the magnetism being added to the effect of the leakage just balances the tendency of the voltage to be increased. If nothing else is done the voltage of the dynamo will remain constant.

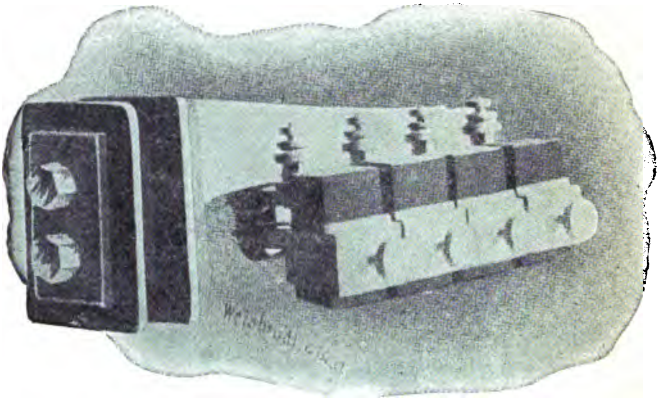


FIG. 449

In the series field, is passing all the current drawn from the machine, and the field strength and voltage tend to increase. This increase is opposed by the C. R. loss in armature and field, and the effect of the increasing field density. The net result is a *building up* of the voltage and if the load is not changed the voltage of the machine will remain constant.

Regulation.—If now in the shunt generator the external circuit is closed, an extra current (very large in proportion to the field current) is drawn from the armature and causes a C.R. loss.

A lower voltage is thus impressed on the external circuit, also on the field. Hence the field weakens, and the added results of C.R. loss and weaker field is a considerable drop in voltage for each increase in load.

Resistance must be cut out of the field as load increases.

When in the series generator the load increases, a shunt should be placed around the field to weaken it, if a constant potential is desired.

Position of the Brushes.—In order that one set of brushes may take away from, and the other set deliver current to the generator in a bipolar machine these sets are on opposite sides of the commutator.

In some dynamos when the inductors come out of the slots, one goes straight on to a commutator bar, and the other is bent over to its proper bar. This puts the brushes in line with part of the coil, and they will be found half way between the pole tips.

It is usual to bend both inductors as they leave the slots and connect to bars half way between the slots. Then the brushes will be found opposite the middle of the pole piece.

In dynamos and non-reversing motors the brushes are a little distance away from the points mentioned, but in reversing motors are exactly at these points.

The alternate brushes are of the same polarity, and there is usually a set of brushes for each field magnet.

The placing of the brushes on the commutator with a certain relation to the winding is necesary as a reference to Fig. 444, or to the diagram of any winding will show that the brush while collecting current is at the same time *short circuiting* one of the coils.

In order that an excessive current may not be generated in this short circuited coil it must be out in the interpolar space at the time the brush touches the two bars belonging to it.

Brushes and Commulators.—Figs. 445 to 449 show different arrangements of modern brushes and brush-holders. These are used to take the current from the commutator and deliver it to the outside wires in the case of a dynamo, and for the opposite in the case of a motor.

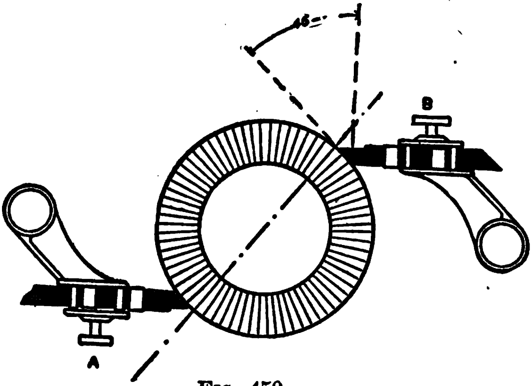


Fig. 450

There are many different designs and constructions of brushes and brush-holders, and these designs are brought about by the various ideas of different builders in their attempt to produce various advantageous results, but the electrical connections and underlying principles remain the same whether a copper or a carbon brush be used.

In any construction of brush holding device, if great care is not exercised in keeping it thoroughly clean, trouble is sure to be the result, and trouble of this nature increases so rapidly that unless the attendant immediately sets about to right it, a burned out armature is almost sure to be the consequence sooner or later. In alternating current dynamos, where brushes rest on collector rings instead of commutators, it is much easier to keep out of trouble, because the brushes in this case merely collect the current from the rings, and do not commutate or rectify it.

The brushes and commutator of a dynamo or motor are probably the most important parts with which the engineer

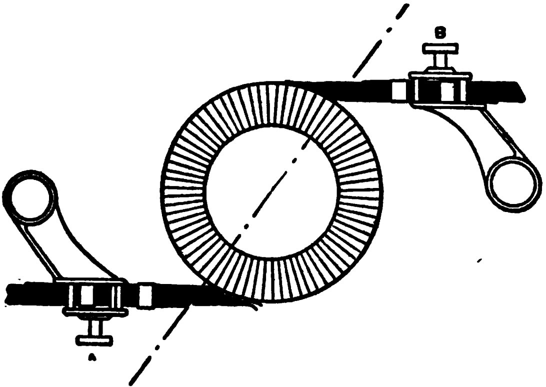


FIG. 451

has to deal. Great care should be taken that the brushes set squarely on the commutator, and that the surface of the brushes and commutator are as smooth as possible. It is a good plan, and in some cases the brush-holders are so made, that the brushes set in a staggering position, that is to say, in a position so that all the brushes will not wear in the same place over the circumference of the commutator and cause uneven wear across the length of the commutator bars. In most machines the armature bearing is arranged so that there is more or less side motion, which, when the armature is running, causes a constant changing of the position of the brushes and commutator.

Whatever style of brush is used, the commutator should be kept clean and allowed to polish or glaze itself while running. No oil is necessary unless the brushes cut, and then only at the point of cutting. A cloth (not cotton waste) slightly greased with vaseline and applied to the surface of the commutator while running is best for the purpose of preventing the commutator from cutting. Should the commutator become rough, it should be smoothed with sandpaper, never using emery cloth, because emery is a conductor of electricity, and the particles of emery are liable to lodge themselves between the commutator bars in the mica and short circuit the two bars, thereby burning a small hole wherever such a particle of emery has lodged itself. The emery will also work into the brushes and copper bars and wear them down; it being almost impossible to remove all the emery.

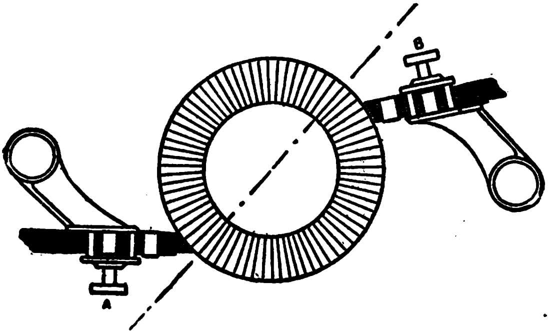


FIG. 452

In the end-on carbon brushes, Fig. 449, the contact surface of the brushes should be occasionally cleaned by taking a strip of sandpaper, with the smooth side of the paper to the commutator, and the sanded side toward the contact surface of the brush, and then by leaving the tension of the brush down on the sandpaper, it is an easy matter to move the sandpaper to and fro and thoroughly clean off the glazed and dirty surface from the carbon, leaving it with a concave that will exactly fit the commutator.

The advantages of carbon brushes are many. Among the cardinal points are: The armature may run in either direction without it being necessary to alter the brushes; the carbon can be manufactured with a quantiy of graphite in its construction, thereby lowering the mechanical friction of the brushes on the commutator; they do not cut a commutator so much by sparking; the commutator has a longer life, the wear being more evenly distributed.

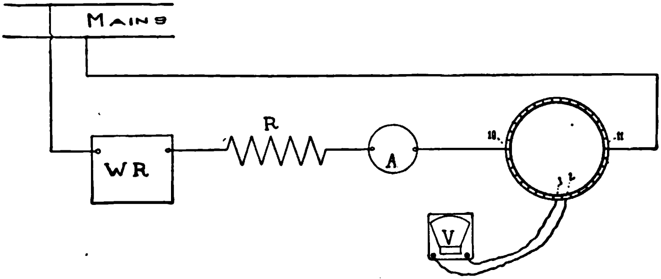


FIG. 453

Carbon brushes, due to their rather high resistance, will often heat up considerably, but, although this heat is objectionable, their resistance tends to cut down the sparking. The brushes are sometimes coated with copper to reduce their resistance. Often a carbon brush will be found which is very hard. As a rule such a brush should be thrown away, as it will heat abnormally and at the same time wear the commutator.

In Fig. 450 we have one of the various so-called old styles of leaf brush-holders. The end-on brushes are more generally used in modern practice, because their contact surface area is not increased or decreased by wear. Consequently the brushes always remain in a diametrically opposite position. With the old style brush-holding device, where the brushes rest on the commutator at a tangent, great care should be exercised not to allow the brushes to wear in a position so that their points will be out of diametrical opposition. Fig. 450 shows the correct setting of this type of brush, and Figs. 451 and 452 show the incorrect setting.

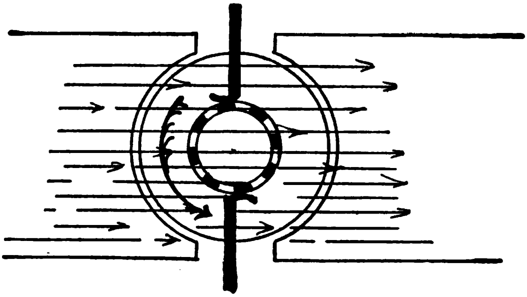


FIG. 454

By remembering that each one of the commutator bars is the end of a coil, and then just mentally tracing the current through the coils from one brush to the other, we can readily understand what the results are when the brushes are neglected and left in a relative position, as shown in these figures.

Sparking is the usual result of brushes allowed to wear to such an extent. Overloading of a dynamo or motor will also cause serious sparking, and no amount of care can prevent damage to armature, commutator or brushes, if a machine is permitted to be overloaded.

Sometimes the commutator will contain one or more bars which, as the commutator gets old and wears down, will wear away either too fast or too slow, due to the metal being harder or softer than the rest of the bars forming the commutator. This causes a roughness of the commutator, and results in the flashing of the brushes and heating of both the commutator and brushes. About the only satisfactory method of remedying this evil is to take out the armature, and have the commutator turned down in a lathe.

A short-circuited coil in the armature, or a broken armature connection, will also cause considerable sparking. Either of these conditions can be located by means of a Wheatsone bridge, or by what is known as the fall of potential method. To make a test with this latter method, connect in series with the armature to be tested some resistance capable of carrying the necessary current, also an ammeter. Some apparatus for varying the current strength, such as a water rheostat, or lamp rack, must be connected in the circuit, a diagram of which is shown in Fig. 453.

In the diagram, WR is the water rheostat or lamp rack, R the known resistance, A the ammeter and M the armature to be tested. By means of the water rheostat regulate the current passing over the apparatus until it is of such strength that a deflection can be obtained on a voltmeter when it is connected to two adjacent bars on the commutator. Suppose the armature coil between bars 1 and 2 on the commutator were broken. The voltmeter connected across these two bars would give the same reading as when connected across the two points 10 and 11. If the voltmeter were connected between any other two points on the commutator on the same side as the broken coil no deflection would be obtained, while connecting the voltmeter between any two adjacent bars on the other side of the commutator would give practically the same reading irrespective of which bars were used. The resistance of one or more sections of the armature winding could also be found by using Ohm's law, R=E/C, or the resistance would be equal to the voltage divided by the current as shown on the ammeter. It must be remembered that this latter will be true only when there is an open coil in one side of the armature, for in this case only will the whole current flow through the one side. If the coil between bars 1 and 2 were short circuited, the voltmeter would show practically no reading between these bars; while between any other bars some deflection would be obtained. An open circuit, or short circuit will nearly always be found by examination, as the trouble usually happens very close to the commutator connections in the case of an open circuit, and may very often be found between the commutator bars themselves, in the case of a short circuit. If the trouble is not at these places it will usually be in the windings, in which case the only remedy is to have it re-wound. Temporary repairs may be made in the case of an open circuit by short circuiting the

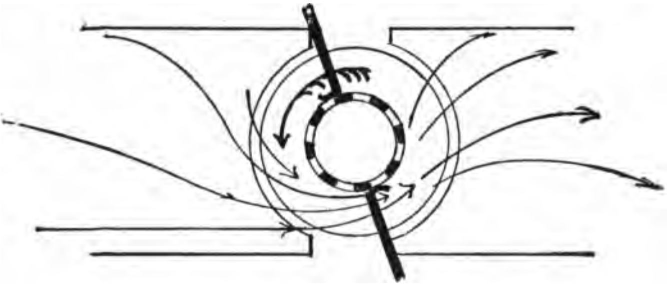


FIG. 455

commutator bars around the open circuit, but this method should only be used in emergency, as the sparking will in time destroy the commutator.

With many dynamos, especially of older types, it is necessary to shift the brushes with every change of load. The current produced by the armature makes a magnet out of it, and the magnetism of the armature opposes that of the fields. In Fig. 454 the armature is working with a very light load and the lines of force of the field magnets are only slightly opposed by those of the armature. In Fig. 455 we assume a heavy load on the dynamo and consequently the magnetism of the armature opposes that of the fields. This changes the location of the neutral point (when the coils under the brush generate no current) and it becomes necessary to shift the brushes accordingly, or great sparking would result. The amount of shifting necessary with changes of load varies in different dynamos. If the field is very strong compared to the armature, it will be but little. If the armature (as in some arc dynamos)

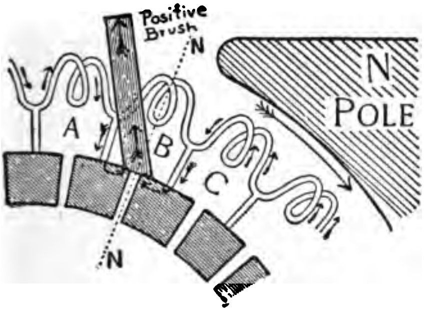


FIG. 456

SHOWING POSITION OF BRUSH FOR SPARKLERS. COLLECTION OF CURRENT

is very strong compared to the field, it will be considerable.

In dynamos, with increasing load, the brushes should be shifted in the direction of rotation, and in the opposite direction when the load decreases.

Never allow a dynamo or motor to stand in a damp place uncovered. Moisture is apt to soak into the windings and cause a short circuit or ground when started. Great care should also be used should it ever be found necessary to use water on a heated bearing. If the water is allowed to reach the armature, or commutator, it is bound to cause trouble. Water should only be used in case of emergency, and then sparingly.

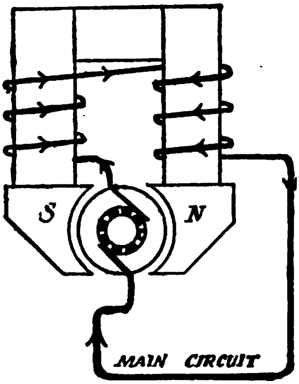


FIG. 457

CIRCUITS IN A SERIES DYNAMO OR MOTOR

Sparking.—When a current is broken there is always a spark, which is greater the more turns in the wire, and the more iron within these turns. That is, the more *inductive* the current the worse the spark.

The conditions are right for excessive sparking in a machine, for the circuit is *inductive* and, although the circuit is not actually broken, the current being merely shifted, yet the result is equivalent to it.

Looking at Fig. 456 and considering the line N N to be about midway between the pole pieces. The coil B is short circuited but has no current in it because:

1. The field is very weak and the coil is moving parallel to it, so no electro-motive force is generated in the coil.
2. The currents from the N- and S-side of winding enter the brush without going through the coil B.

Coil B has therefore no *current* in it, but being connected to A and C whose potential is high, B is *charged* with electricity, and it is full of *coulombs,** which are at rest.

When the armature revolves as shown and the toe of a copper brush leaves bar 3 the current from C must instantly change over going through B to reach the brush. The coulombs in B which are at rest should instantly move at full speed becoming a part of the armature current.

It being impossible to set the coulombs in B into motion instantaneously, it is evident that the current from C encounters *more* than the *ohmic resistance* of the coil B. This extra opposition is called *reactance.*

The path through B being momentarily practically nonconducting, the circuit is broken by the bar moving away from the brush, and a spark or arc formed.

The circuit being *inductive* (having turns containing iron), the spark is persistent and holds until the *reactance* of coil B decreasing, it begins to conduct and diverts enough current into the proper path, and the arc goes out for lack of current to maintain it.

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*A coulomb is a certain quantity of electricity. When a coulomb passes a given point every second a current of one ampere is said to flow.

This *sparking* is avoided in the following way:

1. Carbon brushes of high resistance are used which, as the part of the brush touching a bar gets narrower, due to the high resistance, throttle the current, gradually forcing it over to the coil B. Hence B does not have to instantly carry *all* the current.

2. Move the brushes of a dynamo in direction of rotation until they are nearer the pole shoe, exactly as is shown in Fig. 456.

The short cicuited coil B is now under the *fringe* from the pole piece; and is moving obliquely through a stronger field. A small electro-motive force is generated in it.

From the illustration it will be seen that a current in the same, as in C (for B and C are under influence of same pole piece) flows around through B, the bars 2 and 3 and the brush.

By *shifting* the brushes a little to and fro the correct strength of field can be selected, and the obliquity at which it is cut adjusted, so that a current will be made to flow in B not only of *the same direction as that in C*, but also of exactly the *same value.*

Hence when the toe of the brush slips from bar 3 the current in C instead of running against the *impedance* (the sum of the resistance and reactance) of coil B, finds itself merely falling in behind the flow already established, and there is no tendency to spark.

In a motor the brushes are shifted in opposite direction to the rotation to get the no sparking position. Hence the positions for sparkless forward or backward running are some distance apart.

It is a mere matter of first cost to produce a machine with absolutely *sparkless commutation* under any conditions. It is the skill of the designers which has (without prohibitive cost) so reduced the distance between these two points that it may be spanned by a thick carbon brush.

TYPES OF DYNAMOS.

Dynamos are divided into different types with reference to the manner in which their fields and armature are interconnected.

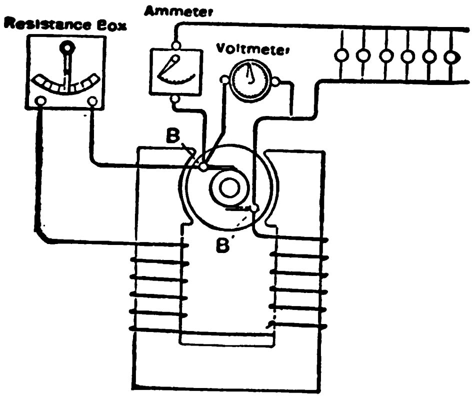


FIG. 458
CIRCUITS OF A SHUNT DYNAMO WITH INSTRUMENTS AND A LOAD OF LAMPS

The series dynamo.—Fig. 457. The same current traverses the field, armature and main or external circuits. The conductors in these circuits are about the same size. The circuits are all in *series*.

This dynamo is used for arc lighting and, as a booster for increasing the pressure on a *feeder* carrying current furnished by some other generator.

The characteristic of this type is to furnish power at an increased voltage as the load increases. If sufficient current is drawn to overload the machine, the voltage will drop.

The shunt dynamo.—Fig. 458. Here the field circuit is arranged as a shunt circuit. The armature and external circuits are in series. The armature current is the sum of the external, and field currents. The conductors on the field are very much smaller than those on the armature, as they carry only 2 to 5 per cent as much current. The shunt dynamo is used for incandescent lamp lighting, and mill and factory power.

The leading characteristic of the shunt generator is to allow the voltage to fall, as the load is increased. It is evident that only by a combination of these two classes into a *compound* dynamo, Fig. 459, can a generator be produced which will deliver any power within its rated capacity, and still hold a steady voltage.

The armature is similar to the armature of the shunt dynamo, but the fields have two distinct windings, one shunt and the other series.

The series dynamo is often called a *constant current* generator because its tendency is that way, and with a regulator it will furnish a constant current.

The shunt dynamo is similarly termed a *constant potential* generator. For with a regulator it will keep to a constant voltage.

If a compound wound dynamo is supplying a circuit at a constant potential it may be almost self regulating. Suppose that the resistance of the external circuit be diminished. This will send more current through the series coil, thus increasing the intensity of the field. But the reduction of the resistance in the outer circuit reduces the current in the shunt winding. This action tends to reduce the intensity of the field.

If the two exciting coils, viz. shunt and series, are properly proportioned, the intensity of the field may be maintained practically constant, even though the resistance of the external circuit is increased or diminished. The armature being kept at a constant speed of rotation, in a constant field of force, by the engine, or other source of power, it will impress upon the circuit a constant voltage. This applies of course to an accurately arranged winding.

Over compounding.—The result of such even action is the maintenance of a constant voltage at the terminals of the machine. In electrical work, all sorts of conditions must be met. A very usual one is that on a circuit a constant voltage is required, not at the generating plant, but in the heart of the district several miles distant. In an over-compounded dynamo the series coil is given a certain number of turns in proportion to the turns in the high resistance shunt coil, and the influence of the series coil overbalances that of the shunt coil. The result of over-compounding is to cause the voltage at the terminals of the machine to rise with the increase of current. The proportional increase of voltage with increase of current can be accurately regulated by the relative sizes of the coils. It is only necessary to follow what has been said regarding the

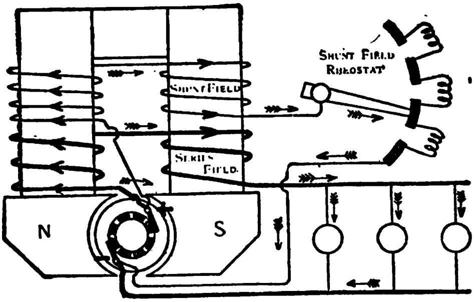


FIG. 459
CIRCUITS IN A COMPOUND DYNAMO

series dynamo, and to regard the compound wound machine as a series dynamo greatly reduced in its characteristic action. Over-compounding makes it possible to maintain a constant voltage at any point within a district. The resistance of the mains between the dynamo in the central station, and the given point in the district is known. The drop in voltage due to that resistance varies with the current. The over-compounding of the machine can be regulated to give the same increase in voltage with the increase in current, and thus the voltage at any desired point in the district can be kept constant, following Ohm's law. Suppose that the resistance of a single lead of the mains is 0.01 ohm. Then the resistance of the two leads is 0.02 ohm. Assuming a maximum current of 500 amperes is needed, the drop due to the specified resistance and current will be $RI=E$, or $0.02\times 500=10$ volts. This is an extreme case, but the dynamo by over-compounding can be made to vary its voltage at the terminals in this, or in any other desired proportion to the current. With the resistance given above, and the variation in voltage for the current as calculated above, which variation is at the terminals, a constant voltage would be maintained at the outer portion of the leads. The series field coils of a dynamo can only be excited by the working current, or by a portion of it. When the machine is compound wound, the series coils are taken care of by the machine, but the shunt coils may receive their current from other sources. But in order to make the dynamo self regulating, the shunt coil should be fed from the machine proper. This practice also makes the dynamo self-contained. In some cases the terminals of the shunt coils are connected to the leads, or bus bars of the main circuit, and if several dynamos are operated, and a constant potential maintained in the circuit at all times, a new element is introduced in the excitation of the field, for the reason that the current in the shunt coil is independent of the speed of the dynamo, and the shunt coils continue to excite the field to a certain extent, and this excitation is never reduced to zero until the connection with the bus bar, or main connection is broken. This is a case of under-compounding, and the advantage of it is that it makes it possible to excite the field before starting the dynamo. The field is not only excited, but the correct polarity is established before the armature begins to revolve. The capacity of the shunt coil is considerable, and it cannot with safety be disconnected by a simple opening of a switch. A bank of lamps is generally mounted in series with it, and the field break switch is placed between the lamps and the main circuit. When it is opened the resistance of the lamps prevents undue sparking. The shunt coil may also be excited by an entirely independent source of electric energy, as a storage battery, or an exciting dynamo. The exciting ma-

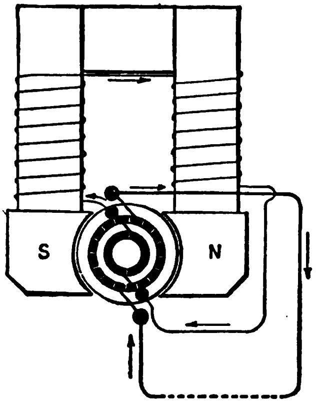


FIG. 460
SEPARATE-CIRCUIT DYNAMO

chine may be run at a constant voltage, thus passing an absolutely constant current through the excited shunt coils.

The separately excited dynamo resembles the magneto in its action, as the field strength does not directly depend upon the current generated. *The separate circuit dynamo* has either two separate armatures in the field space, or it may have two sets of coils. Whichever it is, one armature or coil set is used to excite the field, and the other to supply the current to the circuit. Fig. 460 shows such a dynamo with two commutators, one for supplying the main circuit, and the other the field magnet current.

OPERATION OF DYNAMOS.

Constant Potential Dynamos.—In order to thoroughly explain the operation of dynamos, let us assume that we have the task of starting a new shunt dynamo, one that has never generated any current. Our first step is to open

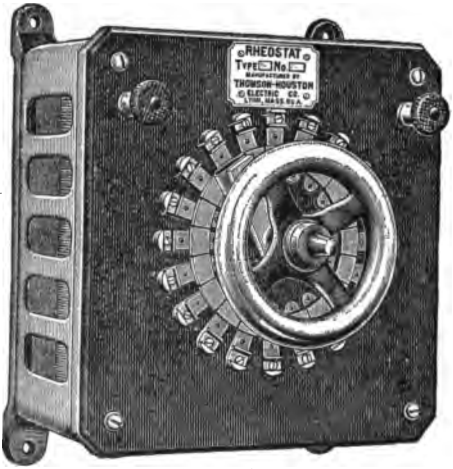

RHEOSTAT
TYPE No.
MANUFACTURED BY
THOMSON-HOUSTON
ELECTRIC CO.
LYNN, MASS. U.S.A.

Fig. 461

the main switch and turn the rheostat or field resistance box so that all the resistance is in circuit. A rheostat consists of a number of resistances, Figs. 461 and 462, so arranged that they can be cut in or out of the circuit without opening the circuit. By reference to Fig. 462, it will be seen that the current enters at the handle, and from there passes to the contact point upon which the handle happens to rest. If the handle is at 1 the current must pass through all the wire in the box; if it is at 2 it simply passes through the handle and out.

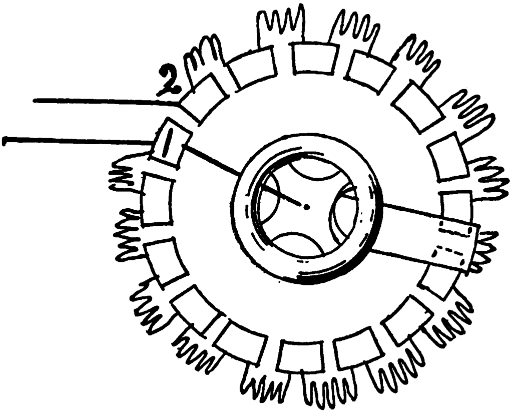


Fig. 462

Rheostats for the shunt circuit of a dynamo should have sufficient resistance, so that when it is all inserted, the voltage of the dynamo will slowly sink to zero. This method of stopping the action of a dynamo is perfectly safe, and should be followed wherever possible.

We are now running our dynamo with all resistance in the shunt circuit. This is simply as an extra precaution because we know nothing about this particular dynamo. When it is known that the dynamo is in good order, the engineer or attendant usually cuts out all the resistance, and as the generator builds up or, in other words, generates current, he proceeds, by the aid of the resistance box, to cut down or diminish the flow of electricity around the field magnets of the dynamo, and thereby diminish the magnetic density of the field magnets, and the electro-motive force of the dynamo.

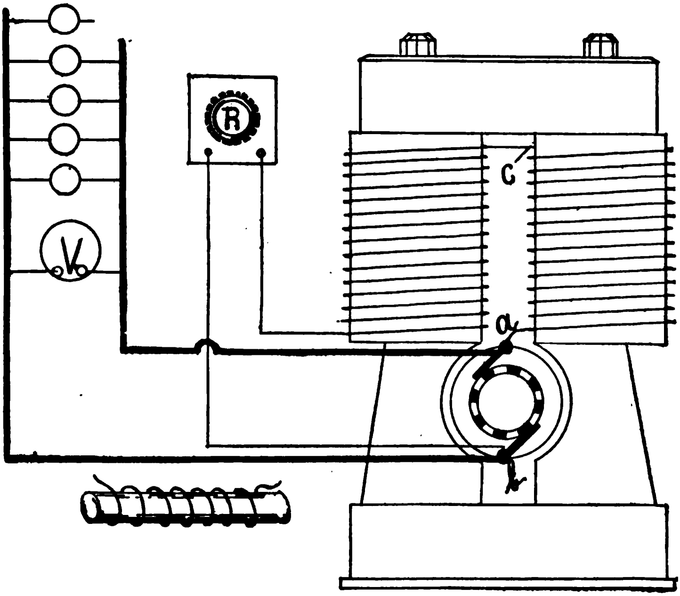


Fig. 463

We must now gradually turn our rheostat so as to cut out resistance, and watch the voltmeter, which is connected as shown at V in Fig. 463, and receives current whenever the dynamo is operating. Suppose that the voltmeter indicates nothing, and we find that the dynamo will not generate. On examination of all the connections we find everything correct, and we now discover that the dynamo field magnets do not contain what is termed "residual magnetism" sufficient to start the process of generating current.

Before an armature can generate current it must cut lines of force, that is, is must revolve in a magnetic field. If the dynamo has been generating current it is likely that the iron cores of the field magnets will retain sufficient magnetism to start the generation of current again. This magnetism which remains in the iron is known as residual magnetism. It will make itself manifest by attracting the needle of a compass, or if strong, a screw driver or a pair of pliers. If we find no magnetism in the iron core of the field magnets, we may take the ends of the shunt winding on the field magnets and pass current over them from a battery. This current will produce sufficient magnetism to cause the generator to build up; in other words, if we disconnect these batteries, and connect the wires back again from where we got them, we will find that we can generate current with the machine.

When the machine begins to generate, we watch the voltmeter, and cut resistance in or out of the circuit according whether we need to lower or raise the voltage. If we have only one dynamo we may close the main switch before we begin generating, or after we have attained full voltage.

Again referring to the pole pieces on the dynamo, it is possible that there is a sufficient quantity of residual magnetism in the pole pieces, and that the polarity of both field magnets, between which the armature is revolving, is the same. This would also cause the dynamo to fail in generating current. If sending battery current through the coils does not make one field a north pole and the other a south pole, one of the fields must be connected wrong and we must make some changes in the connection.

Referring to Fig. 463, *a* and *b* are the terminals of the shunt winding on the fields. If the winding of the fields is correctly put on it will be as in the little sketch at lower corner; that is, if both field magnets were taken out of their places and put together, the winding should run as one continuous spool. But if the winding on one field is wrong, we need simply change its connection, as, for instance, transferring *c* to *a* and *a* to *c*.

In order that a dynamo may excite itself, it is necessary that the current produced by the residual magnetism shall flow in such a direction as to strengthen this residual magnetism. If the current poduced by the residual magnetism flows through the field coils in the opposite direction, it will tend to weaken the residual magnetism, and consequently to reduce the current which flows.

For this reason if the first attempt to start a dynamo with battery current fails, the battery should be applied with the opposite poles so that the magnetism it produces in the fields will be in the opposite direction.

The magnetism, the fields, and all parts of the dynamo may bc in perfect working order, and yet a short circuit in any part of the wiring will prevent the dynamo from building up. This short circuit will furnish a path of such low resistance that all current will flow through it and none can flow through the fields to induce magnetism. Often dynamos fail to generate because of broken wires in the field coils, poor contacts at brushes, or loose connections. Sometimes also part of the wiring may be grounded on the metal parts of the dynamo frame. A faulty position of the brushes may also be a cause for the machine not generating. In some machines the proper position for the brushes is opposite the space between the pole pieces, while in other machines their proper position is about opposite the middle of the pole piece. If the exact position is not known, a movement of the brushes will sometimes cause the generator to build up.

If there are several dynamos to be started great care must be taken to see that the second machine is operating at full voltage before the switch is closed connecting it to the switch board. The voltage should be exactly the same as that of the first machine and the rheostat worked to keep it so. If it is less, it is possible that the first machine will run the second as a motor; if it is more, the second machine may run the first as motor, the machine having the higher voltage will always supply the most current.

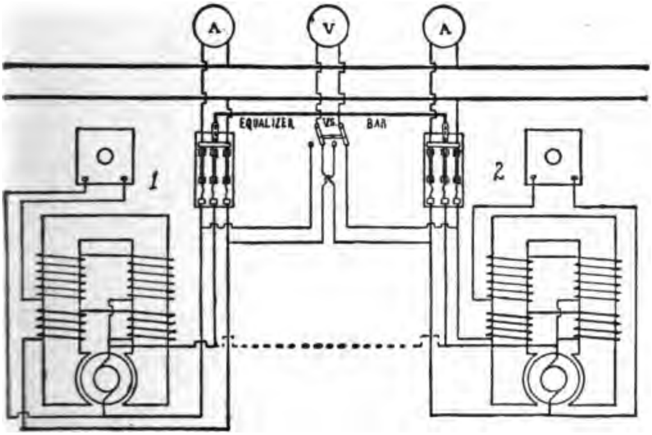


FIG. 464

It is also necessary before throwing in the second machine (connecting it to the switch board) to see that its polarity is the same as that of the machine with which it is to be run. By reference to Fig. 464 it will be seen that the + poles of both machines connect to the same bar, and if one of these machines is running and we wish to connect the other with it, we must first be sure that the wire of the second machine which leads to the top bus-bar is of the same polarity. That is, if the top bus-bar is positive, or sends out current, the wire of all dynamos connected to it must also be positive. The simplest way to find the positive pole of a dynamo is with a cup of water. Take two small wires and connect one to each of the main wires of the dynamo and then insert the bare ends of both wires into the water, small bubbles will soon be seen to rise in the water from one of the wires. That wire which gives off the bubbles is the negative wire. Take care that in making this test you do not get the ends of the small wires together or against the metal of the cup or you will form a short circuit. The polarity of both dynamos must be tested and wires of same polarity connected to the same bus-bar.

Where several machines are to be operated in parallel, compound dynamos are generally used, because it is troublesome to keep two shunt machines working in harmony.

The starting of a compound wound dynamo is the same as that of a plain shunt dynamo, but in connecting a compound wound dynamo to its circuit it is necessary to be sure that the shunt coils and series coils tend to drive the lines of force around the magnetic circuit in the same direction. If the series coil is connected up in the opposite direction to the shunt coil the dynamo will build up all right, and will work satisfactorily on very light loads. When, however, the load becomes even, five or ten per cent. of full load, the voltage drops off very rapidly, and it is impossible to get full voltage with even half the load on. This is because the ampere turns due to the series coils decrease the total ampere turns acting on the magnetic circuit instead of increasing them as the load comes on. This lowers the magnetic flux and of course lowers the resulting voltage. In such a case it will be necesary to reverse either the field or series coils.

Fig. 464 shows connections for two compound wound dynamos run in parallel. When two or more compound wound dynamos are to be run together, the series fields of all the machines are connected together in parallel by means of wire leads or bus-bars which connect together the brushes from which the series fields are taken. This is known as the equalizer, and is shown by the line running to the middle pole of the dynamo switch. By tracing out the series circuits it will be seen that the current from the upper brush of either dynamo has two paths to its bus-bar. One of these leads through its own fields, and the other, by means of the equalizer bar, through the fields of the other dynamo. So long as both machines are generating equally there is no difference of potential between the brushes of No. 1 and No. 2. Should, from any cause, the voltage of one machine be lowered, current from the other machine would begin to flow through its fields and thereby raise the voltage, at the same time reducing its own until both are again equal. The equalizer may never be called upon to carry much current, but to have the machines regulate closely it should be of very low resistance. It may also be run as shown by the dotted lines but this will leave all the machines alive when any one is generating. The ammeters should be connected as shown. If they were on the other side they would come under the influence of the equalizing current and would indicate wrong, either too high or too low. The equalizer should be closed at the same time, or preferably a little before the mains are closed. In some cases the middle, or equalizer, blade of the dynamo switch is made longer than the outside to accomplish this.

The series fields are often regulated by a shunt of variable resistance.

To insure the best results compound machines should be run at just the proper speed, otherwise the proportions between the shunt and series coils are disturbed.

GENERAL RULES.

1. Be sure that the speed of the dynamo is right.

2. Be sure that all the belts are sufficiently tight.

3. Be sure that all connections are firm and make good contact.

4. Keep every part of the machine and dynamo room scrupulously clean.

5. Keep all the insulations free from metal dust or gritty substances.

6. Do not allow the insulation of the circuit to become impaired in any way.

7. Keep all bearings of the machine well oiled.

8. Keep the brushes properly set, and see to it that they do not cut, or scratch the commutator.

9. If the brushes spark, locate the trouble and rectify it at once.

10. The durability of the commutator and brushes depends on the care exercised by the person in charge of the dynamos.

11. At intervals the dynamos must be disconnected from the circuit and thoroughly tested for leakage and grounds.

12. In stations running less than twenty-four hours per day, the circuit should be thoroughly tested and grounds removed (if any are found) before current is turned on.

13. Before throwing dynamos in circuit with others running in multiple, be sure the pressure is the same as that of the circuit; then close the switch.

14. Be sure each dynamo in circuit is so regulated as to have its full share of load, and keep it so by use of resistance box.

15. Keep belting in good order; when several machines are operating in parallel and a belt runs off from one, the others will run this machine as a motor.

16. In the same way if you shut down an engine driving a generator, the other generators will run the generator and the engine.

Constant Potential Switchboard.—Fig. 465 illustrates the usual type of switchboard employed to connect, or switch various dynamos, and to feed various circuits from. These types, sizes and arrangements of switchboards vary, and depend entirely on the type and size of the plant, the number of dynamos used and the number of circuits to be controlled. The switchboard in this cut has three dynamo panels, and one load panel. At the left of the board and near the top is the voltmeter, while on the three left panels are the dynamo main switches and their respective ammeters. On the lower part of these three machine panels will be noticed the protruding hand wheels of the field resistance boxes, which are hidden back of the board. The meter at the top of the right hand panel is the load ammeter and registers the total number of amperes that are being supplied to the circuits whose several switches are just below the meter.

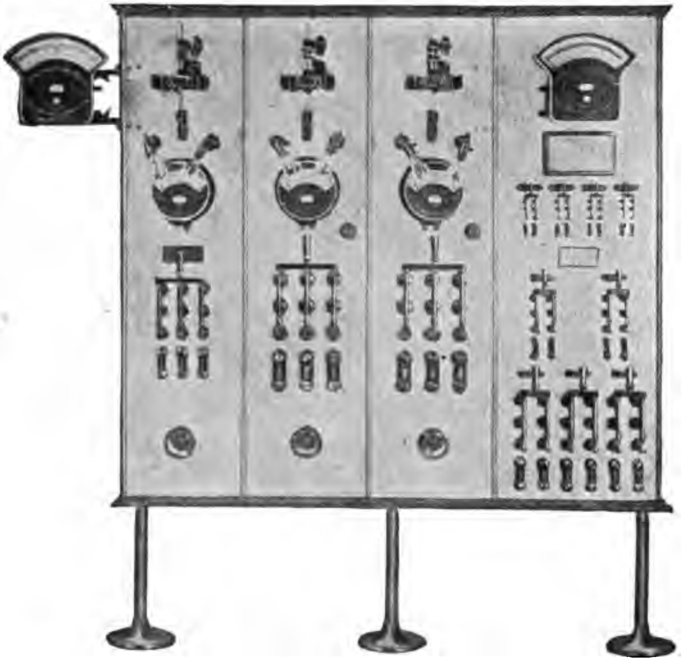


Fig. 465

Fig. 466 shows diagrammatically the reverse side of a similar switchboard. Below all of the switches there are installed fuses in each wire. The object of these fuses is to protect the wires and also the dynamos. These fuses consist of an alloy which melts at a comparatively low temperature. If, for instance, a short circuit occurs in any line, the current will suddenly become very strong and will generate considerable heat. This heat will cause the fuse to melt and open the circuit. If the fuse did not melt, the current would continue and overheat the wires, causing considerable damage and perhaps fires. The fuses should always be chosen of such a size that they will melt before the current rises enough to do any damage.

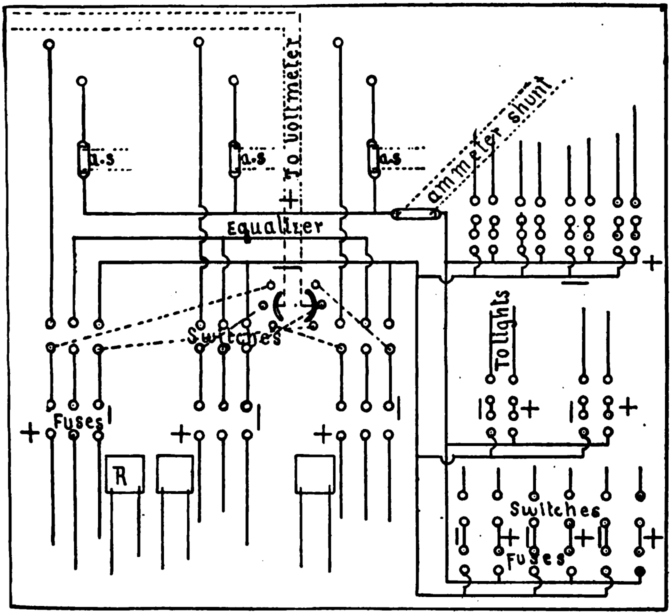


FIG. 466

Operation of Constant Current Dynamos.—Constant current dynamos differ from constant potential dynamos mainly in the higher voltage for which they are usually constructed. Such machines are always more or less dangerous to life, and great care must be taken not to touch any of the current-carrying parts with bare hands.

When such parts must be handled, rubber gloves are very convenient and useful if kept dry. High voltage machines should always be surrounded by insulating platforms of dry wood, or rubber mats, so arranged that one must stand on them in order to touch any part of the machine. By reference to Fig. 467 it will be seen that the constant current dynamo is not equipped either with a voltmeter or a field rheostat; but an ammeter should always be used. The troubles encountered with these dynamos are much the same as those of constant potential dynamos. Most of them are referred to in the following descriptions and instructions for different systems and to avoid repetition need not be mentioned here.

The type of dynamo generally used with constant currents is shown in Fig. 467 and is series wound; that is, the same current that passes through the lights and outer circuit also passes through the fields and excites them. The fields of this dynamo are connected with a short circuiting switch S, which is generally used when the machine is to be shut down. When this switch is closed it forms a path of much lower resistance than do the fields of the dynamo, and all current passing through it and the dynamo loses its magnetism and stops generating. A constant potential dynamo will not begin generating if there is a short circuit anywhere in the wiring connected with it, but with the constant current dynamo it is often necessary to provide a short circuit in order to start it. If there is very much resistance in the line, or if it is entirely open the dynamo will fail to generate.

In order to start generation a small wire may be attached to one of the terminals of the dynamo and the other end brought in contact with the other terminal for a fraction of a second or the shortest possible instant. If the circuit happens to be arranged somewhat as shown in Fig. 467, the plug may be inserted so that the dynamo is started through only one lamp. When this lamp is burning properly the plugs may be suddenly withdrawn

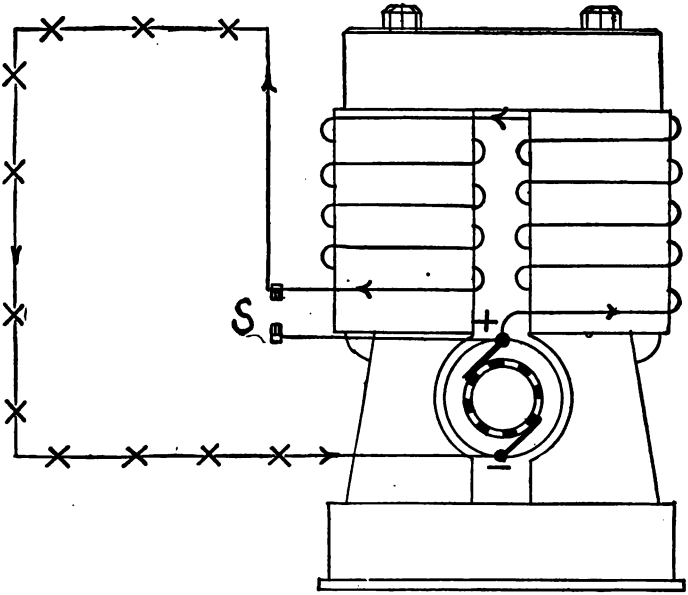


Fig. 467

and the current will now force itself through the other lamps. This process is known as "jumping in" and should be used only in an emergency, as much damage may be caused, especially if a dynamo is already running a large number of lamps and is then "jumped into" a bad circuit. This is also often done, but is just as dangerous as it would be to attempt to start a heavy steam engine by opening up the throttle valve with a quick jerk.

Constant current dynamos are, or should be always equipped with automatic regulators, and before the dynamo is started special attention must be given the regulator to see that it is in proper working order.

Often it may be desirable and even necessary to run two dynamos in series, as, for instance, if a circuit has been extended beyond the capacity of one machine. In such a case the regulator of one machine is cut out, and that machine set to operate at about its highest electromotive force, and the variations are taken care of by the other dynamo.

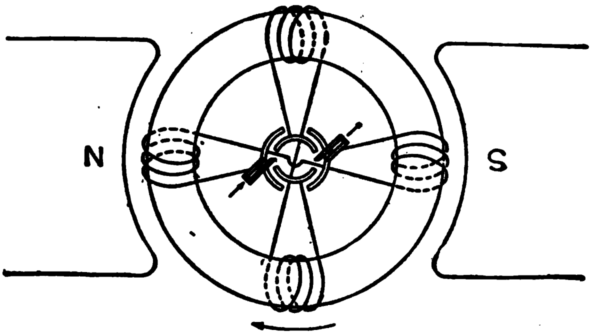


FIG. 468

The Brush System.—The brush arc dynamo is quite distinct from other constant current dynamos in general use. The brush arc generator is of the open coil type, the fundamental principle of which is illustrated in Fig. 468. Two pairs of coils, placed at right angles on an iron core, are rotated in a magnetic field. The horizontal coils represented in the diagram are producing their maximum electromotive force, while the pair of coils at right angles to them is generating practically no electromotive force. The brushes are placed on the segments of the four-part commutator, so as to collect only the current generated by the two horizontal coils. The other coils are open circuited or completely cut out of the circuit.

Such a machine will generate current, continuous in direction, but fluctuating considerably in amount. These fluctuations will be diminished by the addition of more coils to the armature.

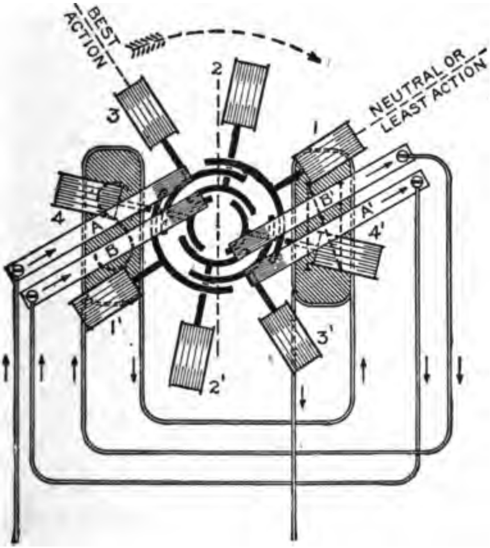


FIG. 469

Fig. 469 shows the connections of an eight-coil brush arc generator. Each bobbin is connected in series with the one diametrically opposite. The connection is not shown on the diagram. It will be noticed that of those coils connected to the outer ring on which the brushes A and A^1 bear, only 3, 3^1 are in circuit, 1, 1^1 being entirely cut out; while on the inside ring all coils 2, 2^1 and 4, 4^1 are in circuit, the two pairs being parallel; 4, 4^1 are coming into the field of best action; in other words, they are approaching that part of the field in which there is most rapid change of magnetic flux, while 2, 2^1 are approaching that part in which the flux is uniform. In 4, 4^1 there is an increasing electro-motive force being generated, and the current is rising; while in 2, 2^1, the electromotive force is decreasing and the current falling. Unless 2, 2^1 were cut out of the circuit a point would soon be reached where the electromotive force in 2, 2^1 would be zero, and consequently 4, 4^1 would be short circuited through 2, 2^1. Just before this occurs, however, 2, 2^1 have passed from under the brush, and the small current still flowing draws out the spark seen on the commutator of all open coil machines.

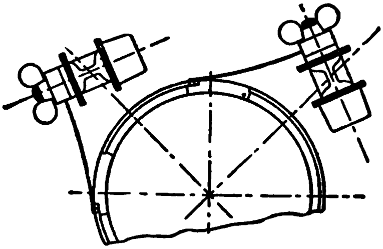


FIG. 470

Setting the Brushes.—A pressure brush should always be used over the under brush in the same holder, as it improves the running of the commutator and secures better contact on the segment. The combination is referred to as the "brush." The brushes should be set about 5⅛ in. from the front side of the brass brush-holder.

In setting the brushes, commence with the inner pair and set one brush about 5⅛ in. from the holder to tip of the brush, then rotate the rocker or armature until the tip of the brush is exactly in line with the end of a copper segment, as shown in Fig. 470. The other brush should be set on the corresponding segment 90° removed (the same relative position on the next forward segment); but if the length of the brush from the holder is less than 5⅛ in., move both brushes forward until the length of the shorter brush from the holder is 5⅛ in. Now set the two extreme outer brushes in the same manner, clamping firmly in position, and by using a straight edge or steel rule, all the brushes can be set in exactly the same line and firmly secured. The spark on one of the six brushes may be a trifle longer than on the others. In this case, move the brush forward a trifle so as to make the sparks on the six brushes about the same length. Equality in the spark lengths is not essential, but it gives at a glance an indication of the running condition of the machine.

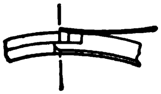


FIG. 471

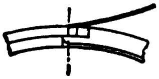


FIG. 472

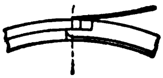


FIG. 473

Brushes should not bear on the commutator less than ⅛ in. from the point of the brush, or, as illustrated in Fig. 471, they will tend to drop into the commutator slots and pound the copper tip of the wood block, causing the fingers of the brushes to break off. If, on the other hand, the bearing is too far from the end, or the brushes are set too long, as in Fig. 472, the point of the brush will not be in contact with the segment, thereby prolonging the break, and allowing the spark to follow the tip with consequent burning of the segments and brushes.

Fig. 473 shows correct setting with the tip of the brush nearly tangential and stiff on the segment as it leaves.

Care of Commutator.—If the commutator needs lubrication, oil it very sparingly. Once or twice during a run is ample. If the oil has a tendency to blacken the commutator instead of making it bright, wipe the commutator with a dry cloth. Too much oil causes flashing.

The machine, of course, generates high potential, and the cloth, or whatever is used to oil the commutator, should therefore be placed on a stick so that the hand is not in any way between the brushes.

A rubber mat should be provided for the attendant to stand on when working around the commutator or brushes.

One hand only should be used, and great care exercised not to touch two brush clamps or brushes at the same time; never with switches closed.

As soon as current is shut off from the machine the commutator should be cleaned. A piece of very fine sandpaper held against the commutator under a strip of wood for about a minute before the machine is stopped, will scour the commutator sufficiently. The brushes need not be removed. An effort should be made to have the machine cleaned immediately after it is shut down. Five minutes at that time will give better results than half an hour when the machine is cold. Never use a file, emery cloth or crocus, on the commutator. New blocks will sometimes cause flashing, due to the presence of sap in the wood. The machine should be run for a few hours with a slightly longer spark, say ½ in., and the commutator then thoroughly cleaned with fine sandpaper.

All constant current arc machines require an automatic regulator to increase the voltage as more lamps are cut into the circuit, and decrease it as lamps are cut out.

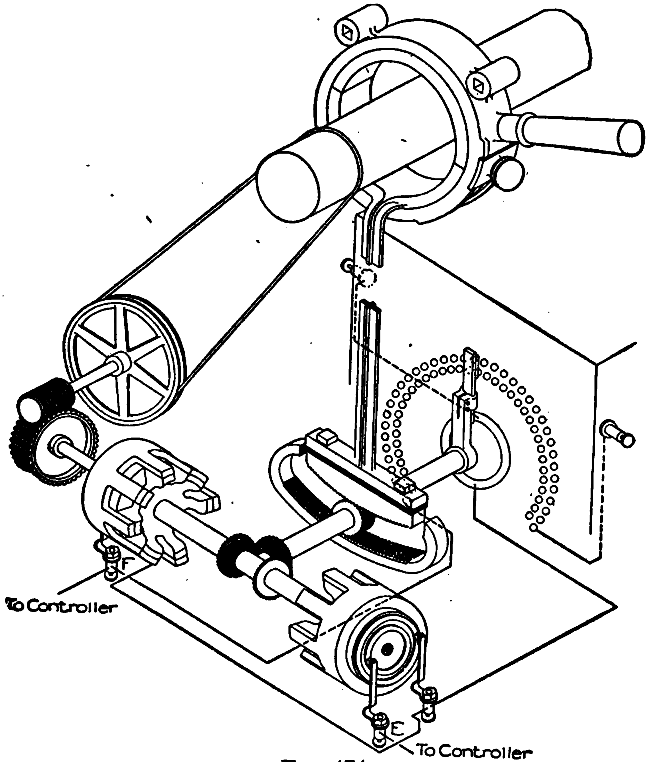
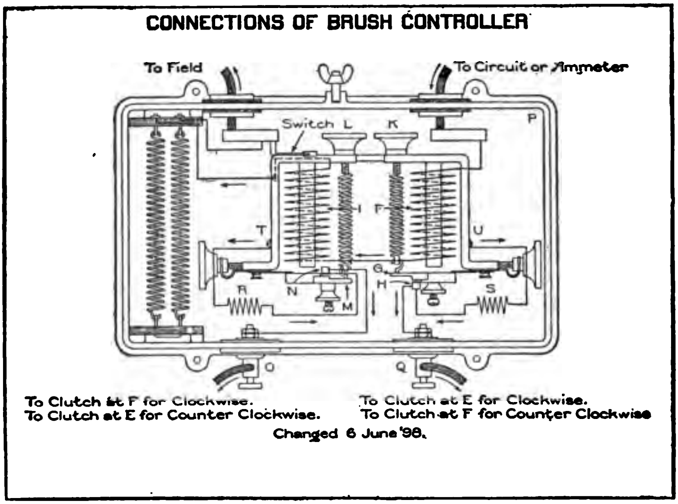


FIG. 474

We will give only one of the several forms of regulators used with this system.

The form 1 regulator is placed on the frame of the machine beneath the commutator, and a constant motion is imparted to its main shaft through a small belt running around the armature shaft. (See Fig. 474.) By means of magnetic clutches and bevel gears, a pinion shaft is rotated, which moves the rack and the rocker arm and so shifts the brushes on the commutator to maintain a spark of about 3/8 in. on short circuit and 1/8 in. at full load; at the same time the rheostat arm is moved over the contacts to cut resistance in, or out of the shunt around the field circuit.


CONNECTIONS OF BRUSH CONTROLLER

To Clutch at F for Clockwise.
To Clutch at E for Counter Clockwise.

To Clutch at E for Clockwise.
To Clutch at F for Counter Clockwise

Changed 6 June '98.

FIG. 475

The current for the magnetic clutches is regulated by the controller.

The controller consists principally of two magnets which are energized by the main current, and act when the current is too high or too low by sending a small current to one of the clutches.

A careful examination of the controller (see Fig. 475), in connection with Fig. 474, will give a clear idea of its regulating action. It is generally advantageous to make the yoke which carries the brushes on the machines, and the arm moving the rheostat, rather tight. As the magnetic clutches act with considerable force, it is not necessary to adjust these moving parts so loosely that they will move without considerable pressure on the rocker handle. Less difficulty will then be experienced in adjusting the controller.

For shunt lamps, the controller may be adjusted to permit a variation of .4 ampere above or below normal; for differential lamps, the variation above and below normal should not exceed .2 ampere. The limits given in the following instructions are for differential lamps, and may be extended .2 ampere above or below for shunt lamps.

If the controller is out of adjustment and fails to keep the current normal, do not try to adjust the tensions of both armatures at the same time. For example, suppose the current is too high, either one of the two spools may be out of adjustment. The left-hand spool I may not take hold quickly enough, or the spool F may take hold too quickly. To make the adjustment, screw up the adjusting button K on the right hand spool, increasing the tension. This will have a tendency to let the current fall much lower before the armature comes in contact with H, to cause the current to increase. By simply tapping the armature G quickly with a pencil or piece of wood, forcing it down to its contact, and at the same time watching the ammeter, the current may be brought up to 6.8 amperes if 6.6 amperes is normal, or to 9.8 if 9.6 amperes is normal. With the current at 6.8 amperes, which is .2 amperes high, the adjusting button L should be turned to increase the tension on this spring until the armature M comes in touch with contact N, which will force current down through O.

The clutch which pulls the brushes forward and rocks the rheostat back for less current will thus be energized. Repeat this adjustment two or three times, but do not touch the adjusting button K; adjust L until it is just right.

At the side of the armature M a little wedge is screwed in by means of an adjusting button, and increases or decreases the leverage on this armature. See that this wedge is fairly well in between the core or frame of the spool and the spring of the armature. The armature M may have to be taken out and the spring slightly bent. It is advisable to have the screw which passes through the adjuster button L about half way in, to allow an equal distance up and down for adjusting this lighter spring after the wedge shaped piece is in the right position to give the necessary tension on the spring which is fastened to the armature M.

In the right-hand corner P, a small bent piece of wire is placed for tightening up the screw which fastens the spring to the frame of the spool. As the contact made by the spring and the frame of the spool held together by a screw and button is a part of the magnetic circuit, it will be almost impossible to get this spring back to exactly the same tension after once removing it. Therefore, the adjusting buttons of the controller must be turned slightly in order to bring it back to its proper adjustment. This, however, is an after consideration, and care should be taken to have the screw which holds the spring and frame together always tight.

Having adjusted the spool I so that the current will not rise above 6.8 amperes (or 9.8 amperes), move the armature M up to contact N with a pencil or piece of wood, causing the current to be reduced to about 6.2 (or 9.2). After the current settles at this point, decrease the tension on the spring which is fastened to armature G, allowing this armature to fall down to contact H. Current will then flow through Q, which will rock the brushes back and also move the rheostat arm for more current. As the spool I has been adjusted for 6.8 (or 9.8) amperes, the current cannot rise above that amount no matter how the spool F is adjusted.

With very little practice in moving the armature of one spool with a pencil, the other can be adjusted much more readily than if an attempt is made to adjust the screws K and L at the same time.

The two small shunt coils R and S, are connected around the two contacts simply to decrease the spark between the silver and platinum contacts. If they should become short circuited in any way, so that their resistances become diminished, sufficient current may pass through either of them to operate the regulator. If unable to locate the trouble disconnect these coils at points T and U, when a thorough examination can be made. M and G need not move more than just enough to open the contact; $\frac{1}{32}$ in. is ample.

In starting the machine, the lower switch, which short circuits the field, should be opened last.

The switch in the left-hand corner of the controller, Fig. 475, cuts out the two resistance wires which are used to force the current through wires O and Q to the clutches. Open this switch, which leaves the automatic device of the controller in circuit, so that it will move the brush rocker. Unclamp the brush rocker from the rheostat arm rocker. Move the brushes by hand to give the proper spark, allowing the rheostat arm, however, to be moved by the controller. After the switches are opened, the rheostat arm will go clear around to a full load position, and then, as the current rises, the controller takes hold and brings the arm back. In the meantime, rock the brushes forward or backward and keep the spark about the proper length, say 1/8 in., at full load to 3/8 in., on short circuit. Gradually the rheostat arm will settle, the spark will become constant, and the machine will give its proper current. Then clamp the rocker and rheostat arm together and let the machine regulate itself.

This method is much better than opening the switches on the machine, and allowing the wall controller to take care of the machine from the start. By allowing the controller to start the machine, a trifle longer spark is obtained than by the other method, unless the machine is run from the beginning on a very full load.

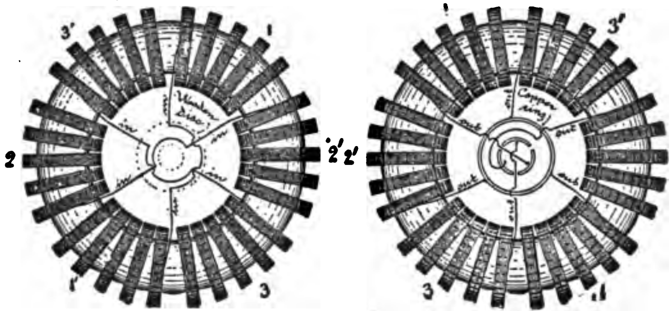

PULLEY END COMMUTATOR END

FIG. 476

The machine will require a trifle longer spark on light load, or on bad circuits, than when running at full load. This fact shuld be borne in mind in wet weather, when trouble with grounds is experienced.

A reliable ammeter should always be connected in the circuit of an arc generator, so that the exact current may be read at a glance. It should be connected into the negative side of the line where the circuit leaves the regulator.

The Thomson-Houston System.—The Thomson-Houston dynamo differs from other arc dynamos principally in the nature of its armature winding. This is shown in Fig. 476. One end of each of the three coils is connected to a copper ring common to all. The other end of each coil terminates at one of the three commutator segments.

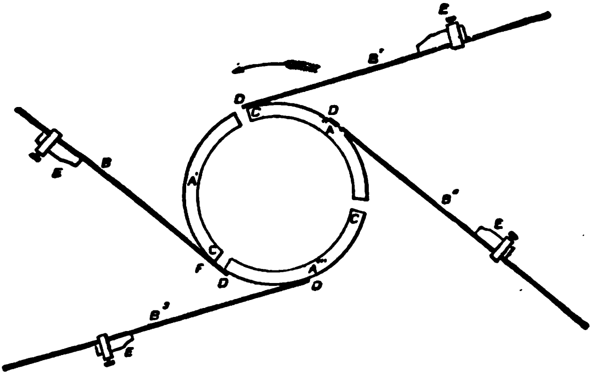


Fig. 477

The following instructions regarding the management, and operation of this machine may prove useful:

Setting the Cut-out.—After the brushes are in position the cut-out must be set. This is done by turning the communtator on the shaft in the direction of rotation (if the commutator is set in position the whole armature must be revolved) until any two segments are just touching the primary brush on that side, as segments A′ and A‴ touch brush B^4 in Fig. 477.

Under these conditions brush B^1 should be at the left-hand edge of upper segment. Then turn commutator until the same two segments are just touching brush B^2, when the end of Brush B^3 should just come to the right-hand edge of the lower segment. If the secondary brush projects beyond the edge of the segment the regulator arm should be bent down; if it does not come to the edge of the segment, the arm should be bent up.

Care must be taken that the regulator armature is down on the stop when the cut-out is being set. These adjustments by bending regulator arm are always made in the factory before testing the machine, and should never be made on machines away from the factory, unless the regulator arm has been bent by accident. If it becomes necessary to make any adjustments they should be made by means of the sliding connection attached to the inner yoke.

Always try the cut-out on both primary brushes. If it does not come the same on both, turn one over. If the brush-holders are correctly set by the guage, there should be no trouble in getting the cut-out set properly after one or two trials.

To set the commutator in the proper position on a right-hand machine, with a ring armature, find the leading wire of No. 1 coil, Fig. 476. It is the custom in the factory to paint this lead red, also to paint a red mark on the center band between two groups of coils, namely, the last half of No. 1 coil and the first half of No. 3 coil. The first half of a coil is that group from which the lead comes. The last half is diametrically opposite the first half, and the lead wire belonging to it is connected with the brass ring on the outside of the connection disk on the commutator end.

In Fig. 478, the first halves of the three coils are represented by 1, 2 and 3, and the last halves by 1′, 2′ and 3′. A narrow piece of tin with sharply pointed ends is bent up over the sides of the middle band at the center of the red mark so that the points are opposite each other.

When the red mark and red lead have been found, turn the armature until the last half of No. 1 coil has wholly disappeared under the left field and until the left-hand edge of the first coil to the right of the red mark (No. 3 in Fig. 478) is just in line with the edge of the left field. The red lead will then be in position shown in Fig. 478 and the armature is in proper position to set the commutator.

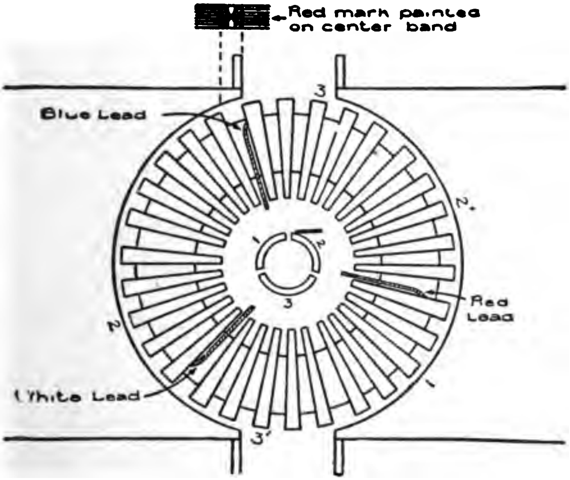


Fig. 478

In the case of the right-hand drum armature, the leading wire of the first coil should be found. This lead may be recognized from the fact that it is more heavily insulated than the rest, and is found in the center of the outer coil, on the commutator end. With this wire turned underneath, rotate the armature forward, or counter-clockwise, until the pegs on the right-hand side of this coil just disappear under the left field. (See Fig. 479.)

The position of the red lead and the red mark on the band are the same on all armatures, but their positions in the fields of the machines called left-hand (clockwise rotation), should be as shown in Figs. 480 and 481 when setting the commutator.

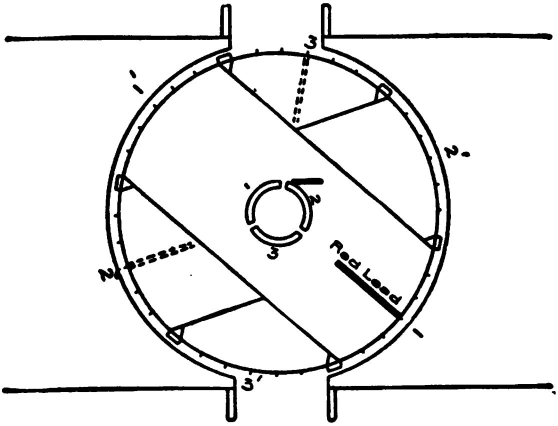


FIG. 479

When the armature of a right-handed machine is in position, the commutator is turned on the shaft until segment No. 1 is in the same relative position as the last half of No. 1 coil; segment No. 2 should correspond with the last half of No. 2 coil, and segment No. 3 with the last half of No. 3 coil, as shown on Figs. 478 and 479.

For left-hand machines, see Figs. 480 and 481.

The distance from the tip of the brush, which is on top, to the left-hand edge of No. 2 segment on a right-hand machine, or to the right-hand edge of No. 3 segment in a left-hand machine is called the lead, and should be made to correspond with the following table.

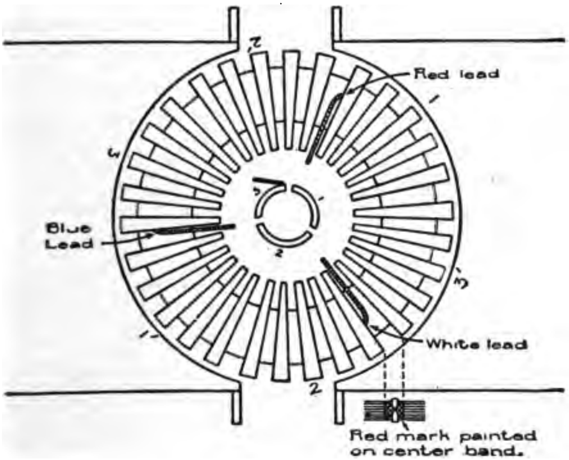


FIG. 480

TABLE OF LEADS.

DRUM ARMATURES.		RING ARMATURES.	
C^{12}	$\frac{1}{4}$ inch positive	K^{12}	$\frac{3}{16}$ inch positive
C^{2}	$\frac{3}{8}$ inch positive	K^{2}	$\frac{1}{8}$ inch positive
E^{12}	$\frac{7}{16}$ inch positive	M^{12}	$\frac{1}{4}$ inch negative
E^{2}	$\frac{1}{4}$ inch positive	M^{2}	$\frac{1}{2}$ inch negative
H^{12}	$\frac{1}{4}$ inch positive	LD^{12}	$\frac{1}{4}$ inch positive
H^{2}	$\frac{1}{4}$ inch positive	LD^{2}	$\frac{1}{8}$ inch positive
		MD^{12}	$\frac{13}{32}$ inch positive
		MD^{2}	$\frac{13}{32}$ inch positive

Place the screws in the binding posts at the lower ends of the sliding connections, and put on the dash pot connections between the brushes, with the heads of the connecting screws outward. In every case the barrel part of the dash pot is connected to the top brush-holder, and plunger part to the bottom brush-holder.

See that the field and regulator wires are connected and that all connections are securely made.

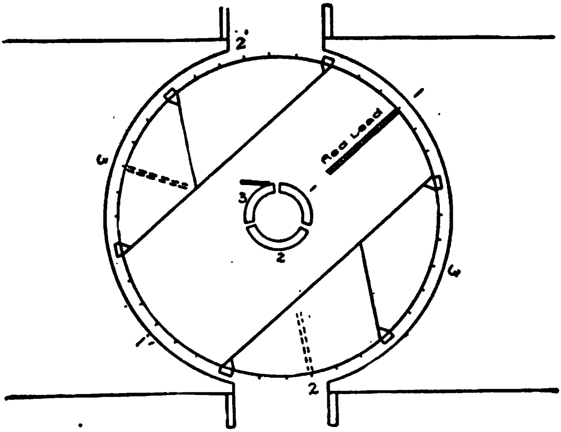


Fig. 481

When all connections have been made, make a careful examination of screws, joints and all moving parts. They must be free from stickiness, and bind in any position.

To determine when the machine is under full load, notice the position of the regulator armature, which should be within 1/8 in. of the stop. At full load the normal length of the spark on the commutator should be about 3/16 in. If it is less than this, shut down the machine and move the commutator forward or in the direction of rotation until the spark is of the desired length. If the spark is too long, move the commutator back the proper amount.

A general view of the complete dynamo is given in Fig. 482, and will help explain the regulator used with this system.

The regulator is fastened to the frame of the machine by two short bolts. On the right-hand machine its position is on the left-hand side, as shown in Fig. 482. On the left-hand machine, *i. e.,* one which runs clockwise, its position is on the opposite side. Before filling the dash pot D with glycerine, see that the regulator lever and its connections, brush yokes, etc., are free in every joint, and that the lever L can move freely up and down. Then fill the dash pot D with concentrated glycerine. The long wire

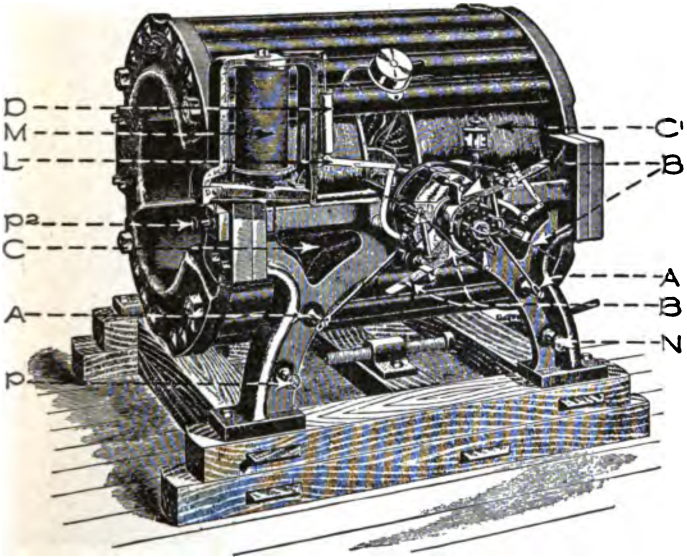


FIG. 482

from the regulator magnet M is connected with the left-hand binding post P of the machine, and the short wire with the post P^2 on the side of the machine. The inside wire of the field magnet, or that leaving the iron flange, of the left-hand field should be connected into post P^2 also, as shown in Fig. 482. The electric circuit (see Fig. 483) should be complete from post P^1, on the controller magnet, through the lamps to the post N on the machine, through the right-hand field magnet C, to the brushes B^1B^1, through the commutator and armature to the brushes B B, through the left-hand field C, to posts P^2 and P, thence to posts P^2 and P on the controller magnet, through the controller magnet to P^1. The current passes in the direction indicated by the arrows.

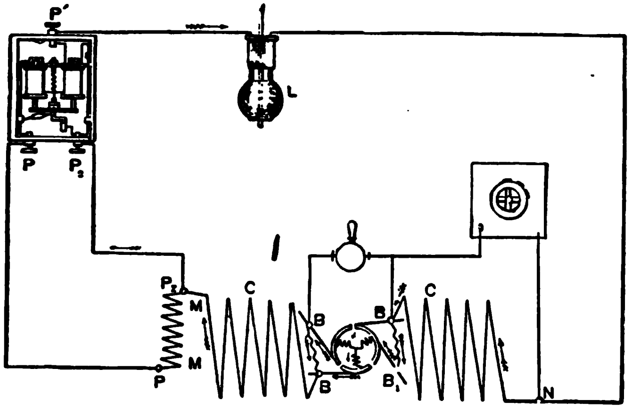


Fig. 483

When an arc machine is to be run frequently at a small fraction of its normal capacity, the use of a light load device is advisable to secure the best results in regulation.

The rheostat for this purpose (see Fig. 484) is connected in shunt with the right field of the generator. Facing the rheostat with the right binding posts at the bottom, the contact on the right side or No. 1 gives open circuit and throws the rheostat out of use. Point No. 2 gives a resistance of 44 to 46 ohms and Point No. 3 gives a resistance of 20 to 22 ohms.

This rheostat with a 75-light machine allows the following variations: Point 1, 75 to 48 lights; Point 2, 48 to 25 lights; Point 3, 25 lights or less. For use with other sizes of generators, the adjustment of the rheostat must be made to suit the conditions.

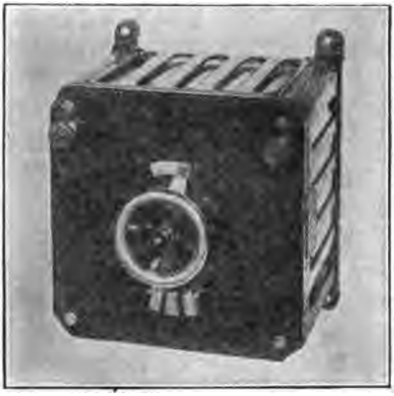


FIG. 484

When the rheostat is in use, the sparks at the commutator will be somewhat larger than normal, but will not be detrimental.

The controller magnet (see Fig. 485) is to be fastened securely by screws to the wall or some rigid upright support, taking care to have it perfectly plumb. It is connected to the machine in the manner shown in Fig. 482, i. e., the binding Post P^2 on the controller magnet is connected to the binding post P^2 (see Fig. 482) on the end of the machine, and likewise the post P on the controller to the post P on the leg of the machine; the post P^1 forms the positive terminal from which the circuit is run to the lamps and beck to N.

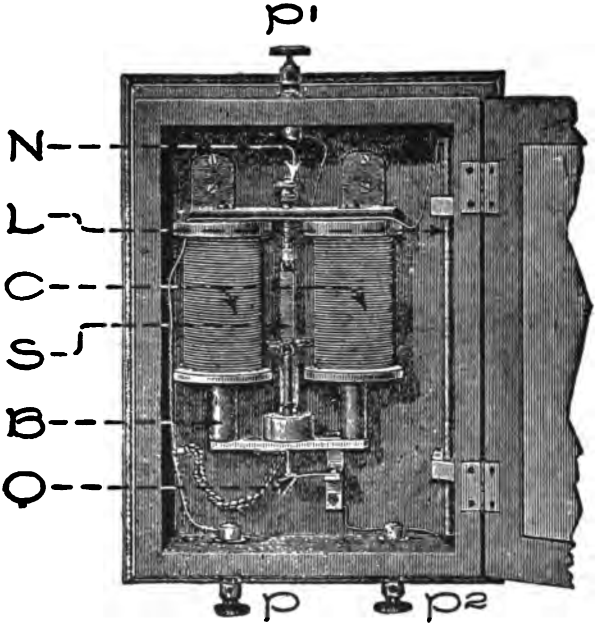


FIG. 485

Great care should be taken to see that the wires P P and P^2 P^2 are fastened securely in place; for if connection between P and P should be impaired or broken, the regulator magnet M would be thrown out of action, thus throwing on the full power of the machine, and if the wire P^2 P^2 should become loosened, the full power of the magnet M would be thrown on, and the regulator lever L, rising in consequence, would greatly weaken or put out the lights.

The wires leading from the controller magnet to the machine should have an extra heavy insulation.

Care should be taken in putting up the controller magnet that the following directions are followed:

1. The cores B of the axial magnets C C must hang exactly in the center, and be free to move up and down.
2. The screws fastening the yoke or tie pieces to the two cores must not be loosened.
3. The contacts O must be firmly closed when the cores are not attracted by the coils C C, which is the case, of course, when no current is being generated by the machine, and when the cores are lifted, the contacts must open from 1/64 in. to 1/32 in.; a greater opening than 1/32 in. has the effect of lengthening the time of action of the regulator magnet. This tends to render the current unsteady, and in case of a very weak dash pot, or short circuit might cause flashing. Adjustment must be made if necessary by bending the lower contact up or down, taking care that it is kept parallel with the upper contact, so that when they are closed, contact will be made across its whole width. If this adjustment is not properly made there will be destructive sparking on a small portion of the contact surfaces.
4. All connections must be perfectly secure.
5. The check nuts N must be tight.
6. The carbons in the tubes L must be whole. These carbons form a permanent shunt of high resistance around the regulator magnet M, and if broken will cause destructive sparking at contacts O, burning them and seriously interfering with close regulation of the generator. In case

a carbon should become broken, temporary repairs may be made by splicing the broken pieces with a fine copper wire.

To keep the action of the controller perfect the contacts O should be occasionally cleaned by inserting a folded piece of fine emery cloth and drawing it back and forth.

The amount of current generated by each machine depends upon the adjustment of the spring S. If the tension of this spring is increased, the current will be diminished, if the tension is diminished the current will be increased.

In starting these dynamos when the armature has reached its proper speed, the short circuiting switch on the frame should be opened. This method allows the generator to take up its load gradually, and is a very important point in the handling of the machine.

ELECTRIC MOTORS.

The doctrine of the conservation of energy already referred to in this volume, may safely be regarded as the corner stone of engineering science, and in nothing is it better illustrated than in the reversibility of the dynamo, and motor. When the armature of a dynamo is caused to revolve within the field of force, by mechanical power, resistance will be encountered if the circuit is closed, and the result is that the mechanical energy is absorbed, and converted into electrical energy, the presence of which is easily detected by the heating the wires, and other means. Energy is conserved.

In the electric motor, this action is exactly reversed. Electrical energy is absorbed, and mechanical energy is supplied by it. In engineering practice an electric machine (dynamo or motor), often automatically changes from motor to dynamo, or the reverse, and in some cases serious trouble results, if the change is not detected in time.

Any dynamo may be used as a motor and consequently we have as many types of motors as there types of dynamos. The pull of a motor depends upon the repulsion and attraction between the lines of force, or magnetism of the wire, and core of the armature, and that of the fields. We have seen that in a dynamo, as we force a wire through a magnetic field, current is generated. The more current there is generated, or flowing in such a wire, the greater will be the expenditure of power necessary to force such a wire through a magnetic field; in other words, the currents flowing in the wires of a dynamo armature, always tend to drive the armature in a direction opposite to that in which it is being driven.

If, then, instead of revolving a dynamo armature by machanical means, we connect it to a source of electricity and allow a current to flow through it we must obtain motion, and the direction of this motion will depend upon the direction in which the current flows, so long as this current does not alter the magnetism of the fields.

The electric motor is built exactly like a dynamo; consequently, as its armature revolves it not only does useful work, such as turning whatever machinery it is belted to, but it also generates an electromotive force. For instance, if a motor, running at full speed and receiving current from a dynamo (Fig. 486), were suddenly disconnected by opening the main switch, it would at once begin acting as a generator and sending out current. This can be easily seen with any motor equipped with a starting box, such as shown; for the current from the motor will continue to energize the fields, and the little magnet M so as to hold the arm of the starting box until the motor has nearly come to rest. If it were not for the current generated by the motor, this arm would fly back the instant the switch is opened.

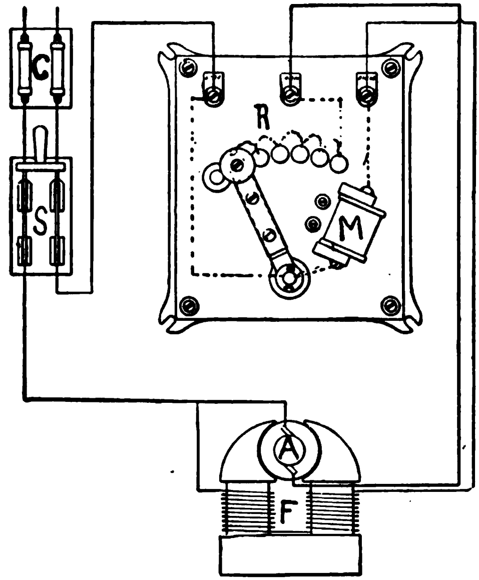


FIG. 486

The electromotive force set up by a motor always opposes that of the dynamo driving it; that is, the current which the motor tends to send out would flow in the opposite direction to that which is driving it.

This may be compared, and is somewhat similar, to the back pressure of the water which a pump is forcing into a tank. If the check valves were removed and the steam pressure shut off, the water would tend to force the pump backward.

This electromotive force is called the counter electromotive force of the motor. The counter electro-motive force of the motor varies with the speed of the motor, and also limits the speed of the motor, for it is obviously impossible that a motor should develop higher counter E. M. F. than the E. M. F. of the dynamo driving it.

The highest possible speed of a motor is, then, that speed at which its counter E. M. F. becomes equal to the E. M. F. of the dynamo supplying the current, and this is the speed which would be obtained were the motor doing no work and running without friction. This condition is impossible in practice, and the counter E. M. F. of the motor is always less than the E. M. F. of the dynamo. To speed up a motor it must run faster in order to develop an E. M. F. equal to that of the dynamo. This may be done by lessening the number of turns of wire on the armature, or by lessening the magnetism of the fields. In doing so, however, the capacity of the motor for performing work is also lessened.

The power that can be obtained from an electric motor depends upon two things: the current flowing in its armature coils, and the strength of magnetism developed in the fields.

Assuming the fields as remaining constant, the power of the motor must then vary as the current flowing through it. Suppose we have a motor being driven by an E. M. F. of 110 volts and it is doing no work; it will be running at full speed and its counter E. M. F. will therefore also be very near 110 volts. If now a load be thrown on this motor, it must get more current in order to develop the necessary power to carry the load.

Throwing on the load will decrease the speed of this motor, and consequently its counter E. M. F. will fall, say to 100 volts. The E. M. F. of the dynamo being 110 and the counter E. M. F. of the motor 100, there will be considerable current forced through the armature of the motor, so that it can now handle the load.

The current in the armature at all times will equal $\frac{E - E'}{R}$ where E is the electromotive force of the dynamo, E′ the counter electromotive force of motor, and R the resistance of the motor armature. In order that a motor should keep a nearly uniform speed, for varying loads, the resistance of its armature should be very low, for then a slight drop in counter E. M. F. will allow considerable current to flow through the armature. The above applies particularly to the shunt motor shown in Fig. 486. In this diagram C is a double pole fuse block, S the main controlling switch, R the starting box, or rheostat, M the magnet, which holds the arm of the starting box in place when it is brought over against it, F the fields, and A the armature of the motor.

The current enters, say at the right hand fuse, and passes to the starting box and along the fine wires shown in dotted lines through the fields of the motor and coil M to the other fuse. The fields of the motor and the little magnet M are now charged, but as yet there is no current passing through the armature and no motion. We now slowly move the arm on the starting box to the right; this admits a little current, limited by the resistance in the starting box, to the motor armature and it begins to revolve, and as we continue to move the arm to the right, the armature gains in speed because we admit more current to it by cutting out more and more resistance. When the armature attains full speed, the arm comes in contact with the little magnet M, and is held there by magnetism. The whole object of the starting box is to check the inrush of current, while the armature is developing its counter E. M. F. or back pressure.

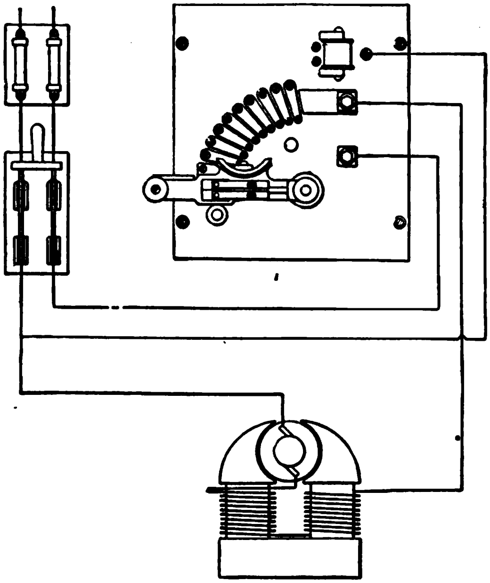


Fig. 487

When the armature has attained its normal speed, the starting box is no longer in use. If for any reason the current ceases to flow, the little magnet M loses its magnetism and releases the arm, which (actuated by a spring) flies back and opens the circuit so that, should the current suddenly come on again, the sudden inrush will not damage the armature.

In Fig. 487 are shown the connections of a series wound motor with an automatic release spool on the starting box of a sufficiently high resistance so that it can be connected directly across the circuit. This becomes necessary since the field windings are in series with the armature.

The speed of a series motor may be decreased by connecting a resistance in series with the motor, and may be increased in speed by cutting out some of the field windings. In electric railway work where two motors are used on one car, they are usually connected in series with each other in starting up, and then in parallel with each other while running at full or nearly full speed. The series motor is well adapted to such work as electric railway work, or for

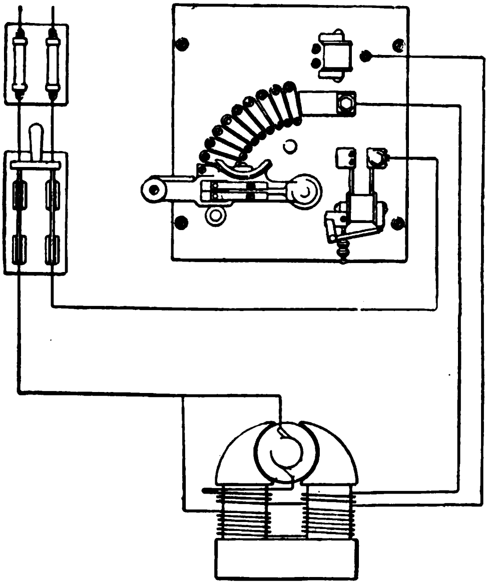


FIG. 488

cranes and so forth, because it will automatically regulate its speed to the load to be moved, exerting a powerful torque at a low speed while pulling a heavy load. Such a motor, however, requires constant attendance when the load becomes light, as it will tend to "run away" unless its speed is checked.

In Fig. 488 we have a diagram of a compound wound motor connected with a type of starting box that cuts out the armature when current has been cut off the lines supplying the motor, as before explained. In addition to this there is another electro magnet which is traversed by the main current on its path to the armature. Should the motor be overloaded by some means, the current flowing to the armature would exced the normal flow. The magnetism thus produced would overcome the tension of a spring on the armature of the so-called "overload magnet" and cause it to short circuit the magnet which holds the resistance lever, and allow it to fly back and open the armature circuit. By so doing the liability of burning out the armature due to overload is reduced to a minimum.

The compound motor may be made to run at a very constant speed, if the current in the series winding of the fields is arranged to act in opposition to that of the shunt winding. In such a case an increase in the load of a motor will weaken the fields and allow more current to flow through the armature without decreasing the speed of the armature, as would be necesary in a shunt motor. Such motors, however, are not very often used, since an overload would weaken the fields too much and cause trouble.

If the current in the series field acts in the same direction as that of the shunt fields, the motor will slow up some when a heavy load comes on, but will take care of the load without much trouble. Fig. 489 shows a starting box arranged as a speed controller. It differs from other starting boxes only in so far that the resistance wire is much larger, and that the little magnet will hold the arm at any place we desire, so that if we leave the arm at any intermediate point the motor will run at reduced speed. This sort of speed regulation can be used only where the load on the motor is quite constant. If the load varies, the speed will vary. Another and a better way of varying the speed of motors consists in cutting a variable resist-

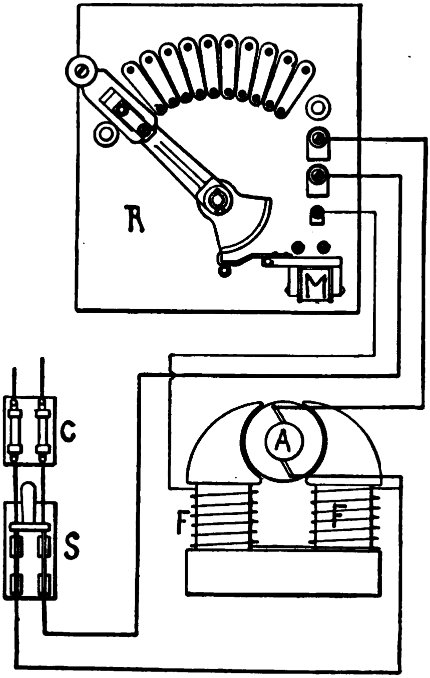


FIG. 489

ance into the field circuit, because as more resistance is cut into the circuit the fields become weaker and the motor speeds up. If possible, motors should be so designed that they can operate at their normal speed, and they will then cause little trouble.

Motors have much the same faults as dynamos, but they make themselves manifest in a different way. An open field circuit will prevent the motor from starting, and will cause the melting of fuses or burning out of an armature. The direction of rotation can be altered by reversing the current through either the armature or the fields. If the current is reversed through both, the motor will continue to run in the same direction. A short circuit in the fields, if it cuts out only a part of the wiring, will cause the motor to run faster and very likely spark badly. If the brushes are not set exactly opposite each other, there will also be bad sparking. If they are not at the neutral point, the motor will spark badly. Brushes should always be set at the point of least sparking. If it becomes necessary to open the field circuit, it should be done slowly, letting the arc gradually die out. A quick break of a circuit in connection with any dynamo, or motor is not advisable, as it is very likely to break down the insulation of the machine.

The ordinary starting box for motors is wound with comparatively fine wire and will get very hot if left in circuit long. The movement of the arm from the first to the last point should not occupy more than thirty seconds, and if the armature does not begin to move at the first point the arm should be thrown back and the trouble located.

Alternating Current Motors.—By a proper combination of two phase or three phase currents it is possible to produce a rotating magnetic pole. By placing inside of the apparatus which produces this rotating magnetic pole, a suitable short circuited armature, this armature will be dragged around by the rotating pole in much the same way that a short circuited armature in a direct current machine would be dragged around if the fields were revolved. Such a machine is called an induction motor. The armature will revolve without any current entering it from the external circuit. This does away with commutators, collector rings, brushes, brush-holders, and in fact many of the parts which are so necessary in direct current machines.

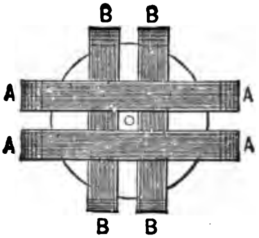


FIG. 490
ROTARY FIELD COILS

The rapidity of the alternations in the external circuit determines the speed of the motor.

Synchronous Motors.—Some alternating current motors are known as "synchronous" motors. What is meant by synchronous is, occurring at the same time, or in unison. As an example, suppose two clocks are ticking just alike so that the pendulums start and stop at the same time; we would hear but one tick. These two clocks would then be in synchronism. If an alternating current generator has 32 field coils and revolves at the rate of 60 R. P. M., then a synchronous motor with only 4 field coils would revolve at the rate of 480 R. P. M. This motor would operate in synchrony with the generator, and yet would make 480 R. P. M. while the generator made 60 R. P. M.

The production of the rotary field is the main reason for the generation of polyphase currents.

Fig. 490 shows four coils of wire. Assume that the coils B B receive an alternating current, and the coils A A receive another current in quadrature with the first. Then when the current in B B is at maximum, the current in A A will be at minimum, and as the current in B B decreases, the current in A A will increase.

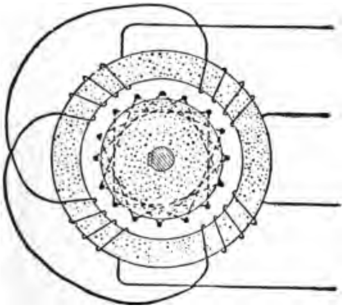


FIG. 491

TWO PHASE ROTATING FIELD COIL AND ARMATURE

When the B current is at maximum, there will be established N and S magnet poles on a horizontal axis passing through the center of the B coil. The A coils when active will establish poles on an axis perpendicular thereto.

Poles at intermediate points will also be established when current is passing through all four coils. The result of this arrangement is that north and south poles are kept traveling around the circle by the alternating currents acting in quadrature with each other, meaning that the angle of lag and lead between the two current waves is 90° or a quarter circle.

Currents of this kind constitute a two phase alternating current and the changes occur about 100 times per second. Fig. 491 shows a cylindrical laminated core wound with a re-entrant coil, and mounted on bearings within the field. This core will rotate because the alternating currents passing through the field coils will induce currents in its wires, owing to their rotary field of force.

In order to establish in the core the polarity above described, the lines of force must be cut by its windings. Consequently it lags behind, and its revolutions per minute are from 5 to 10 per cent slower than those of the rotary field. If it were made to synchronize with the field it would have no induced polarity, and no pull or torque would be exerted upon it. Therefore, it constantly falls behind, and the amount of this drop is termed its slip. Fig. 492 is a diagrammatic view of the generation of a three-phase current, and the operation by it of an induction motor. Following the lines and numbers will show that the stator of the motor receives the same currents that are induced in the stator of the generator.

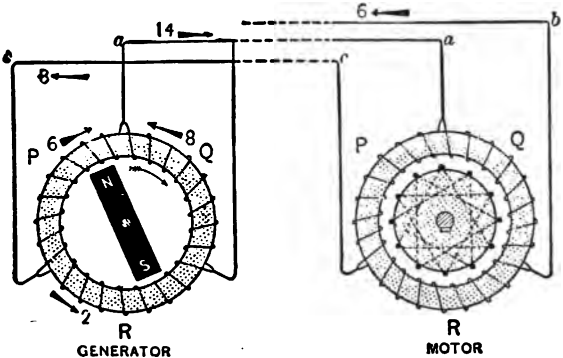


FIG. 492

THREE PHASE GENERATOR, AND INDUCTION MOTOR

But the poles of the generator travel around it, the result being that a rotary field is produced in the stator of the generator. Fig. 493 represents a four-pole, three-phase generator driving such a motor.

There are 12 armature coils, three sets marked A, B, C, for each pole of the generator, thus giving a three-phase current. They are connected in Y combination. The generator is shown on the left, the field being the rotor.

The motor is shown on the right of the diagram, and it also has 12 coils marked as in the generator, and Y connected. The generator and motor are connected by the three wires a, b, and c, the fourth wire being omitted, as it would have no load to carry. The large letters on the armature indicate the course of the windings. The three-phase current produces a rotary field, on the same general principle as does the two-phase current. The lag of the currents behind each other acts to cause the poles resulting from the combined action of the coils, to rotate around the field. Motors constructed upon this principle are termed induction motors, and the coils on the armature (which is the rotor), are self-contained, having their ter-

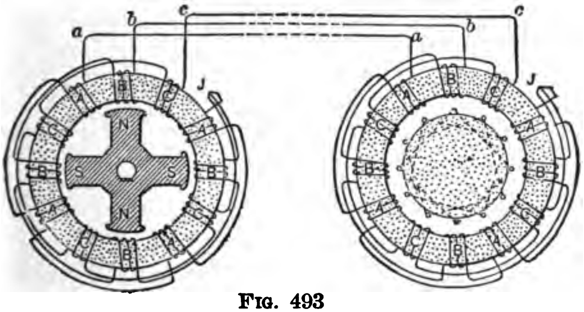


FIG. 493

FOUR-POLE THREE-PHASE GENERATOR AND INDUCTION MOTOR minals connected so that the winding is re-entrant, and has no outside connection whatever. Fig. 494 shows such a motor complete. The rotary field referred to in the foregoing description should not be confounded with the revolving field. In the rotary field the rotary action is purely electrical, the poles simply rotating around the circle, there being no rotation of any part of the mechanism. But a re-

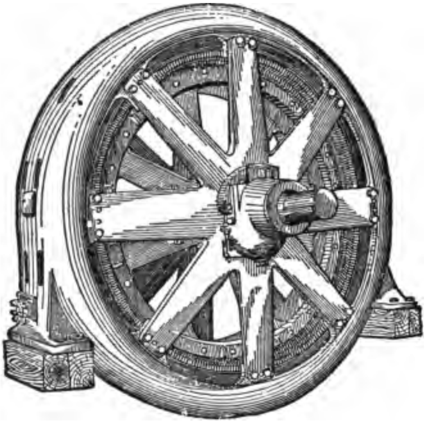


Fig. 494

INDUCTION MOTOR WITH SQUIRREL CAGE ARMATURE

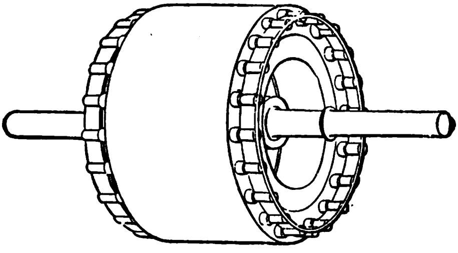


Fig. 495

SQUIRREL CAGE ARMATURE

volving field is entirely different. It revolves on an axis like a wheel. The student should remember this, as there is danger of confusion in the use of the two terms. A combined rotary, and revolving field may be obtained by a simple modification of the mechanical structure, in which the field is mounted on journals, and the armature is stationary. Fig. 495 shows the squirrel-cage armature of an induction motor, the core being laminated, and having straight conductors of copper lying in the longitudinal grooves close to its surface. The ends of these conductors are connected to two rings of copper.

QUESTIONS AND ANSWERS.

714. What is electricity?

Ans. Electricity is an invisible agent. Its exact nature is not very well known, although the laws governing its action, the methods of controlling it, and the effects produced by it are becoming well known.

715. Is it correct to use the term quantity with reference to electricity?

Ans. It is. We may use terms to designate definite quantities of electricity, passing through a conductor, in the same way that we speak of gallons of water flowing through a pipe.

716. Is it proper to assume that there are large quantities of electricity stored for future use, in a manner similar to water?

Ans. It is not, except in a limited sense, as in storage batteries.

718. Define the doctrine of the conservation of energy.

Ans. The total quantity of energy in the universe is unalterable. When energy is expended, or disappears in one form, it must reappear in another form.

719. In accordance with this doctrine, what would be the proper term to apply to electricity with reference to the physical requirements of man?

Ans. It is a useful agent for the rapid transmission of stored up energy in fuel, water falls, etc.

720. What is the practical unit of quantity used in speaking of electricity?

Ans. The coulomb. It is that quantity of electricity that would pass in one second through a circuit carrying a current of one ampere.

721. What is an ampere?

Ans. It is the unit of volume, or rate of flow. A current of one ampere will flow through a circuit whose resistance equals one ohm, when the electro-motive force, or pressure behind it equals one volt.

722. What is a volt?

Ans. The volt is the unit of electro-motive force, and represents a pressure that will cause the flow of one ampere through a circuit in which the resistance equals one ohm.

723. What is an ohm?

Ans. The ohm is the practical unit of electrical resistance. It is that amount of resistance that would limit the flow of electricity under an electromotive force of one volt, to a current of one ampere, or to a discharge of one coulomb per second. It equals the resistance of a column of mercury one sq. millimetre in area of cross section, and 104.9 centimetres in length.

724. What is the unit of work?

Ans. The foot pound.

725. What is the unit of power, or rate of doing work?

Ans. The foot pound, per second.

726. How is the amount of work that electricity is capable of doing, measured?

Ans. By the volt-coulomb, or Joule. The amount of electrical work per second is equal to the volt ampere, or watt.

727. What amount of power developed is represented by the watt?

Ans. 44.25 foot-lbs. of work per minute, or 0.7375 foot-lbs. per second.

728. What is a magnet?

Ans. A mineral consisting of a combination of iron and oxygen.

729. What is the chemical formula of a magnet?

Ans. Fe^3O^4.

730. What is a permanent magnet?

Ans. A piece of steel that has been charged with magnetism, and retains it.

731. What is meant by the poles of a magnet?

Ans. All magnets tend to point north and south, the same end always pointing in the same direction; hence the end pointing north is called the north pole, and the end pointing south is termed the south pole.

732. What peculiar characteristic attaches to the poles of magnets?

Ans. The north poles of two magnets tend to repel each other, and the same is true of the south poles. But the north pole of one magnet attracts the south pole of another, like repels like, and unlike attracts unlike.

733. What is an electro magnet?

Ans. A bar of iron surrounded by a coil of wire through which an electric current is passing.

734. What are lines of force?

Ans. They are certain imaginary lines passing through the steel of the magnet from its south pole to its north pole, and issuing from the latter they curve around through space and return to the south pole.

735. What is the magnetic circuit?

Ans. It is the path of these lines of force, around and through the magnet. It resembles a closed curve, either a circle, or an ellipse.

736. Explain the difference between the magnetic circuit and the electric circuit.

Ans. The magnetic circuit, or field of force, that surrounds a magnet is maintained without the expenditure of energy, while on the other hand an electric current passing upon its circuit develops energy, and energy must be expended to maintain it.

737. Are there any other points of difference between the two circuits.

Ans. Yes, the electric current passes through a conductor in intensity proportional to the electro-motive force urging it, while the magnetic circuit passes through air, or a vacuum in proportion to the magneto-motive force urging it.

738. What is meant by the term potential as applied in electric practice?

Ans. Voltage or pressure.

739. What is the law of induction?

Ans. When a conductor is moved in a magnetic field of force so as to cut the lines of force, there is an electromotive force impressed on the conductor in a direction at right angles to the direction of motion, and at right angles to the direction of the lines of force.

740. What is a dynamo?

Ans. A machine for transforming mechanical energy into electrical energy.

741. How is the field of force maintained in a dynamo?

Ans. By means of electro-magnets.

742. Does not this require the expenditure of energy?

Ans. Yes; a certain amount of energy is indirectly expended.

743. How are dynamos classified?

Ans. Into two grand divisions, viz., direct current dynamos and alternating current dynamos.

744. What is direct electrical current?

Ans. A current of unchanging direction.

745. What is an alternating current?

Ans. A current that reverses its direction of flow, periodically, from 20 times and upward per second.

746. Name the principal constituent parts of a dynamo.

Ans. The armature, the field, the collecting rings, or commutator, and the brushes.

747. How is electro motive force or current induced in a dynamo?

Ans. By rapidly changing field and armature relations by means of mechanical energy.

748. How is the output of a dynamo stated?

Ans. In Kilowatts equal to 1,000×volts×amperes.

749. How is the output of a motor stated?

Ans. In horse power, equal to Watts intake÷746×efficiency expressed decimally. (Not as a percentage.)

750. What is the voltage of a dynamo? of motor?

Ans. It is the pressure that the generator or alternator delivers at its own terminals. The voltage of a motor is the voltage which should be applied to its terminals in order to develop full horse power.

751. What is full load current of dynamo? of motor?

Ans. Full load current of a dynamo is that current which may be drawn steady for 24 hours without causing any part of the machine to exceed a safe temperature, i. e., 150° Fahr. This applies to factory motors.

752. What is meant by the rating of a dynamo? Of a motor?

Ans. The product of full load current multiplied by the voltage expressed in Kilowatts is rating of a dynamo. The actual mechanical horse power developed at the pinion of the motor as tested in shop.

753. What is the armature core?

Ans. The sheet iron body which carries the armature winding, and conducts the flux from pole piece to pole piece.

754. What is the armature spider?

Ans. The casting consisting of hub and arms which supports armature core.

755. What are binding wires?

Ans. They are narrow bands of phosphor bronze wire placed around the armature every three or four inches to help bind the winding to the core. They rest on strips of mica, and are sweated with solder all around.

756. What are commutator segments?

Ans. The commutator segments or bars are the copper pieces of which the commutator is built.

757. What are commutator leads?

Ans. They are the ends of the armature winding extending from the core to the lug of the commutator bar.

758. What are pole pieces?

Ans. The end of the magnet core nearest the armature. Usually larger than the core.

759. What are magnet cores?

Ans. The iron inside the field coil.

760. What is the yoke?

Ans. The part of magnetic circuit connecting the magnet cores.

761. What is the pitch of an armature winding?

Ans. It is the number of teeth between the two sides of a formed coil plus one tooth.

Example: The two sides of a coil are in slots number 3 and 17, then pitch is 14.

762. Is there insulation between winding and core?

Ans. Yes. Mica or fuller board; there is also the tape on coil.

763. What insulation is there between conductors of winding?

Ans. The double cotton covering of each wire makes four thicknesses between conductors.

764. What is the air gap?

Ans. It is the air space between armature and pole pieces. In dynamos it is made as small as possible for efficiency.

In motors it is not made too small because this tends to make the machine spark due to the weak field. In D. C. series motors it is from ⅛ to ¼ of an inch, in A. C. series motor it is smaller, say 1/10 to ⅛ inch.

The larger the air gap of a motor the more the bearings may wear before there is danger of the armature rubbing against the lower pole pieces.

765. What are field spools?

Ans. The brass shells on which the field coils are wound.

766. What is the commutator?

Ans. It is a series of copper bars placed parallel to the shaft, insulated from each other and from the frame of the machine. Each is connected to the winding and current flows from the winding through them to the brushes. It at the same time reverses the connections between the brushes and the winding at the proper times so that the brush always collects current.

767. What is a collector or slip ring?

Ans. A collector consists of two or more rings of copper placed around the shaft and insulated from it, and each other. Each is connected to a part of the winding. The brushes rest on the rings.

They are used to collect current from a revolving armature style of alternator, to feed current into armatures of rotary converters, or the revolving fields of alternators.

The collector has no corrective influence and passes on the A. C. or D. C. current exactly as it receives it.

Single phase machines have two rings; two, three, and six phase machines have three rings.

768. Is there a difference between no load and full load voltage of dynamos?

Ans. Yes. A shunt dynamo gives highest voltage at no load and lowest at overloads; the series dynamo gives lowest at no load and highest at full load. The compound dynamo is a combination of series and shunt, and gives same voltage at all loads.

An alternator acts like a shunt dynamo.

769. What is a field rheostat?

Ans. It is a resistance in the field circuit which can be varied to change the current, and hence the field strength. This alters the voltage of the dynamo.

770. What are commutated fields?

Ans. In some motors the field coils are arranged in sections so that they may be arranged in parallel, or series, or in combinations.

All coils in parallel give the greatest current and hence slowest speed of motor; all coils in series give the weakest field and the fastest speed.

771. What relation has field strength to the speed of motor?

Ans. The weaker the field the faster the speed, for the motor must revolve fast to generate its proper counter E. M. F.

772. What relation has armature strength to the speed of motor?

Ans. The greater the armature current the higher the speed.

773. What effect on the power of motor does field, and armature strength have?

Ans. The greater the field and armature current the greater the power.

774. What is a ring winding?

Ans. One which passes over and under around the core, a space being left between the shaft and core to accommodate the winding.

775. What is a drum winding?

Ans. One where all winding is on the outer surface of the core.

776. Upon what does sparkless commutation of current depend?

Ans. (1) The more commutator bars the better, there being less voltage and therefore tendency to spark between bars. The average railway motor has from 100 to 125 bars on commutator.

(2) The fewer the ampere turns on the armature in comparison to the ampere turns on the field the less sparking.

(3) The more turns short-circuited by the brush when touching two or more bars at once, the greater the tendency to spark.

777. What is a shunt field?

Ans. One whose coils are placed as a shunt across the brushes. It carries a small current.

778. What is a series field?

Ans. One which carries the main, or nearly all the main current, and is placed in series with the armature. A small strip of resistance metal is used sometimes to divert a portion of the main current from the series field.

779. What are Foucault, or eddy currents?

Ans. Local currents set up within the armature, and acting as a hindrance to the generation of useful current.

780. How may the electro-motive force be increased?

Ans. By increasing the speed, or by adding more turns or loops of wire to the armature winding.

781. What is meant by self excitation of a dynamo?

Ans. When the dynamo is standing still, the field magnets become weakly magnetic, but when the armature begins to revolve a few volts of electric current will be sent through the field coils, gradually increasing the magnetic strength until full voltage is reached.

782. What is a series dynamo?

Ans. One in which the same current that travels the main circuit also traverses the field.

783. Explain the action of the shunt dynamo.

Ans. The field circuit is a shunt, and only a portion of the main current passes through it.

784. How are the fields of a compound dynamo excited?

Ans. The fields have two distinct windings; one shunt, and the other series.

785. What advantage pertains to the compound wound dynamo?

Ans. It is practically self-regulating.

786. What is the difference between the dynamo and the electric motor?

Ans. Practically none in the principles governing the design of the machines. Any dynamo may be used as a motor, and vice versa.

787. State the difference in their functions.

Ans. The dynamo converts mechanical energy into electrical energy, while the motor converts electrical energy into mechanical energy.

788. Upon what does the power to be obtained from a motor depend?

Ans. Two things, viz., the current flowing in its armature coils, and the strength of magnetism developed in its fields.

789. How is the speed of motors controlled?

Ans. By a starting box or rheostat.

790. How may the direction of rotation of a motor be reversed?

Ans. By reversing the current through either the armature or the fields.

791. Upon what principle does the alternating current motor act?

Ans. Upon the principle of induction, having for its main accessory the rotary field.

792. How is a rotary field produced?

Ans. By the use of polyphase currents.

793. Explain the meaning of the term rotary field.

Ans. In a rotary field the rotary action is purely electrical, the poles simply rotating around the circle. There is no rotation of the mechanism of the field.

794. What then is a revolving field?

Ans. A field that revolves around an axis like a wheel.

Electric Currents

Reference having been frequently made in the foregoing pages to different kinds of electric currents, such as direct, alternating, two and three phase, etc., it is now in order to give a short explanation of their leading characteristics. *The direct current* is in a measure explained by its title direct, meaning that it travels in the same pressure direction straight from the generator to the locality where it does work, and then back again to the generator, over the return wire. The natural tendency of the current generated in all dynamos is to alternate, that is it starts at a value of zero, rises to a maximum of one polarity, descends to a value of zero again, and changing in direction of pressure, attains a maximum of opposite polarity, from whence it returns to zero again, these alternations being constantly repeated over and over again. In the direct current generator the alternating electro-motive force producing this current is reversed or commuted at the proper instant by means of the commutator, and brushes, and the result is that a one direction electro-motive force, having a constant fixed potential or voltage, is impressed upon the external circuit.

The alternating current. In order to get a clear conception of the true nature of the alternating current it is absolutely necessary that the student should comprehend, and bear in mind the meaning of the different terms used in alternating current practice, such as volts, amperes, frequency, phase, and power-factor. These will be taken up and discussed in their logical order, with reference to their practical meaning, omitting as much as possible all theoretical, and mathematical deductions. The voltage, or pressure in an alternating current does not have a constant fixed value, as in the direct current system, but is continually changing in amount, and alternating in the direction of pressure at equal, regular intervals of time. Reference to Fig. 496 will serve to explain the action of the alternating electro-motive force within the generator, and also the action of the alternating current produced by it. The horizontal line having degrees from 0 to 360 marked upon it represents the line of zero values or no voltage. The lengths of the vertical lines correspond to the distance of points of the curve from the horizontal or zero line. The left hand quadrant of the generating circle is divided into angles of 22½° or one sixteenth of a circumference. For each angle lines are drawn, such as M P. On the zero line, divisions corresponding to the angles are laid off, and ordinates erected upon them. Each sine determines the length of the ordinate corresponding to its angle, as for instance the sine M P of 45° determines the length of the ordinate M P erected on the second (or 45°) of the sixteen divisions of the zero line.

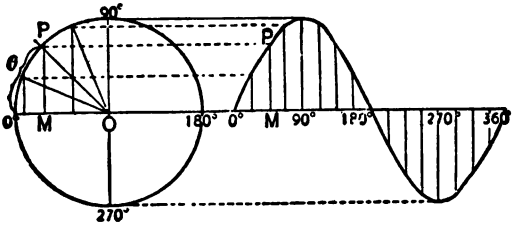


Fig. 496

SINE CURVE OF GENERATING CIRCLE.

The sines as drawn in Fig. 496 represent the values of the E M F from zero to 90° or one quarter of the generating circle, and the length of the ordinate erected upon the 90° point of the zero line corresponds to the highest voltage value of the current wave above the zero line. The portion of the wave above the line may be assumed to represent the positive pole, and the portion below the line the negative pole.

It will easily be seen that if sines are drawn in each quadrant of the circle, the lengths of the ordinates for the remaining parts of the wave curve may be determined from them, and thus a true representation of one complete wave, or cycle, be obtained.

In the alternating current dynamo the current is sent to the line exactly as it is generated in the armature, flowing out one wire, and back on the other and then reversing, and flowing out on the wire on which it has just flowed in, and back on the wire on which it had formerly flowed out. An illustration which will more fully explain this action can be found by supposing the two ends of the cylinder of a piston pump were connected by means of a pipe and then, having done away with all the valves except the suction valves, the pump was started. At the beginning of the stroke, water would be forced out one side of the cylinder around the pipe into the other side of the cylinder, and after the piston had reached the end of the stroke and started back, the water would then take a return course back to where it had started. In this case the pump could be likened to the dynamo, and the pipe to the wires, and the current to the water flowing back and forth. As the water pressure in the pipe will fluctuate, reaching maximum at one point in the stroke, and zero at another point, so also when the alternating current wave reaches its point of highest voltage or pressure the whole circuit is affected, and when it reaches zero value, the whole circuit is at zero. The expression wave should be clearly understood. It means that the whole circuit passes simultaneously through the values of the cycle represented in the wave curve. The number of waves per second is called the frequency of the current, therefore when we speak of a frequency of 60 we mean that it requires one-sixtieth of a second for the voltage to pass through a complete cycle, or in other words 60 cycles are completed in one second. By alternations is meant simply the change in direction of pressure, or voltage, of the current, and it will be seen by reference to Fig. 497 that two alternations occur in each complete cycle, one at C, and the other at E, (assuming that we start at zero value of A). Alternations are usually expressed in terms of the number per minute, as for instance 7,200 alternations means 60 cycles per second; for since there are two alternations per cycle, the number of cycles per minute will be 7,200÷2= 3,600, and the cycles per second, or frequency will be

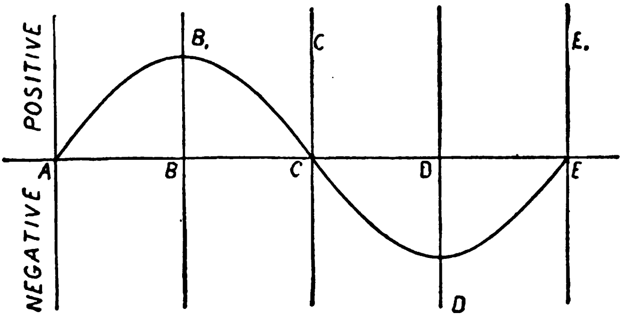


Fig. 497
CHANGES IN AMOUNT AND DIRECTION OF PRESSURE

3,600÷60=60. The following table gives the alternations corresponding to the usual commercial frequencies:

Frequency.	Alternations.
25	3,000
50	6,000
60	7,200
133	16,000

The action of the alternating current as represented in Figs. 496-497 can be considered as continuing indefinitely in the same regular order, and in the same intervals of time. Referring to Fig. 497, the curved line AB′, CD′ E represents the alternating voltage as it rises at A to a positive maximum value at B′, then falls to zero at C, where the direction of pressure is reversed, and the same maximum value of the voltage in the negative direction is reached at D′ when it again falls to zero at E. The word "period" is sometimes used to designate the time in seconds or fractions of a second required to pass through a complete cycle, and the number of periods per second is termed the frequency. We have so far considered only the voltage wave but in actual practice the volt-meter does not indicate the peak of the voltage wave, but rather that of the current wave, which is usually about 0.707 or roughly speaking .7 of the maximum voltage. For instance, when the volt-meter reading is 110 volts, the maximum value at the peak of the wave will be 155 volts, nearly. The pressure indicated by the volt-meter is the effective voltage, and it is with this voltage value that the engineer is concerned in every-day work.

The maximum voltage is important to the station man only in testing insulating materials, and in the design of line insulators on high tension transmission lines. As in the case of the volt-meter, the ordinary alternating ammeter measures about 70.7 per cent of the maximum value of the amperes at the peak of the current wave. The ammeter reading of effective current produces the same heating effect, gives out the same available energy as a direct current of the same amount. When there is no apparatus with an iron magnetic circuit connected to an alternating current system, such as induction motors, arc lamps, etc., the current wave will begin to rise with the voltage wave, reach its maximum value at the same instant as the voltage does, and complete the cycle in exact time relation with the voltage. Fig. 498 shows both the voltage and the current waves, the zero line being divided into 360° as in Fig. 496. The full line represents the voltage wave, and the dotted line the current wave. In commercial alternating current work the choking action or "inductance" as it is called which results from the presence of the iron magnetic circuit, caused by the connection of the electrical apparatus with the main circuit, and in which apparatus there is more or less iron surrounded by, or enclosing coils, causes the

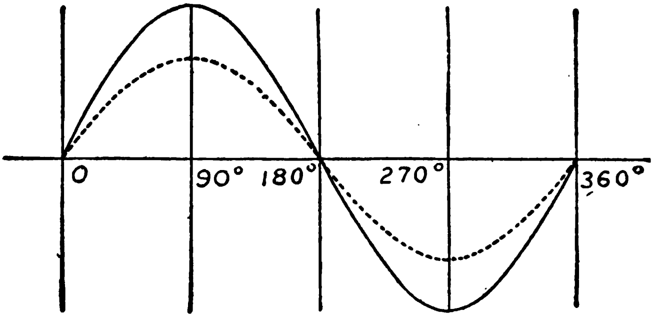


Fig. 498
VOLTAGE AND CURRENT WAVES

current wave to lag behind the voltage wave, that is the zero, maximum, and all intermediate values of the current will follow a certain interval of time, or a certain number of electrical degrees, behind the corresponding values of the voltage.

Phase, Lag, and Lead.—The term phase is employed to denote the relative position of a current wave with respect to the wave of electro-motive force producing it. Fig. 498 shows voltage and current in phase, that is the waves of both are in unison, both starting at zero, and reaching their maximum values at the same instant. If however the current lags behind the voltage, as shown by Fig. 499, it is said to be out of phase, and the amount of this lag in degrees is called the angle of lag, and depends upon the nature of the load, being greatest for a load of induction motors, and series arc lamp.

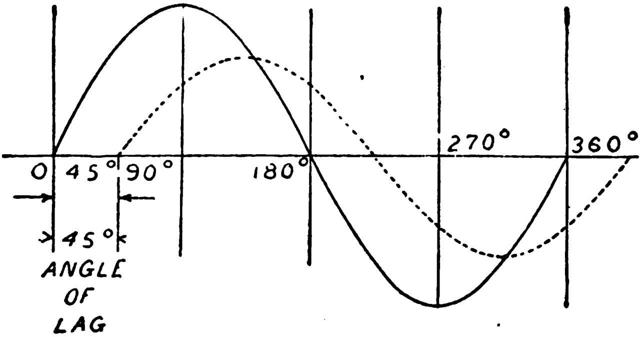


FIG. 499

CURRENT LAGGING 45 DEGREES BEHIND THE VOLTAGE

In Fig. 499 the current wave (dotted line) is shown as lagging 45 electrical degrees behind the voltage wave (full line), and in this case the angle of lag is 45°.

In some cases, especially in the operation of rotary converters, and synchronous motors, the current wave may be ahead of, or lead the voltage wave. This is caused by an action directly the opposite of inductance, called capacity, and is illustrated in Fig. 500, where a current lead of 15 electrical degrees is shown, and in which the angle of lead is 15°. In the alternating current-generator the field coils occupy about 50% of the surface of the field bore, because when their inner edges are tight together, their outer edges are apart, due to the larger circumference at the pole pieces, and because some interpolar space must be left to prevent excessive leakage from pole to pole.

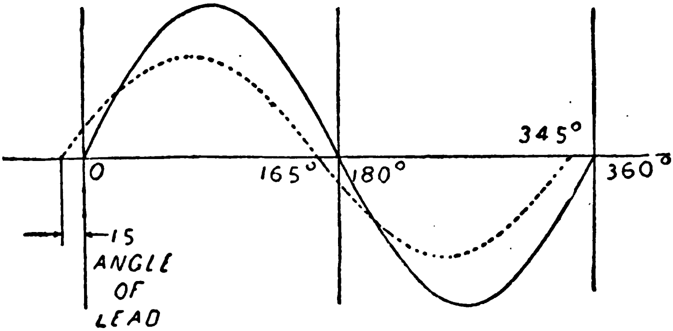


FIG. 500
SHOWING A CURRENT LEAD OF 15 DEGREES

Only 50% of the armature bore is wound, for otherwise the coils would be so wide that they would extend over into the field of a wrong pole piece. If one side of a coil is under a N-pole the other side should be under a S-pole. Then the two electro-motive forces induced, add together. Should the coil be so wide as to extend over to the next N-pole any electro-motive force induced by that pole would be subtracted.

There is then on the ordinary alternator half of the armature empty. Such a machine is called a Single Phase Alternator.

Two and Three Phase.—It occurred to some inventor that an entirely separate winding could be put on between the coils of the original winding, and be connected to its own collector. The current was to be led to a different circuit, but it soon became evident that it was better to make of the four wires from the alternator, a three-wire circuit by joining two of them inside the armature and leading out three wires to the switchboard. Such an alternator is a Two Phase Alternator.

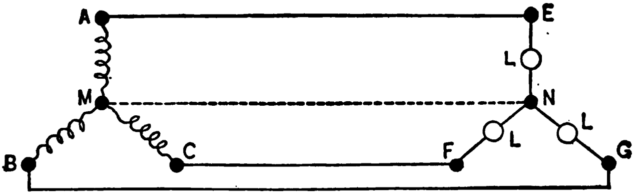


FIG. 501
3-PHASE Y CONNECTION

Of course the capacity of the machine is not doubled, because from a single phase alternator is drawn enough current to heat it to the safe limit. From a two phase alternator we do the same thing. The reason we gain in capacity is because in a single phase machine the heating is concentrated, while in the two phase machine it is evenly distributed all over the armature.

Even in a two phase alternator there is a portion of the armature not used for winding, and there was still a desire to reduce the number of line wires. This led to the Three Phase Alternator.

The three armature windings of the alternator are connected together at one point, and the other ends to the three collector rings, or the three windings are connected in series and the three points where they are joined are connected to the three collector rings.

The former winding is called a Y winding and is shown in Fig. 501. The latter is a Δ (Delta) winding and is shown in Fig. 502. The European names are respectively Star and Mesh windings.

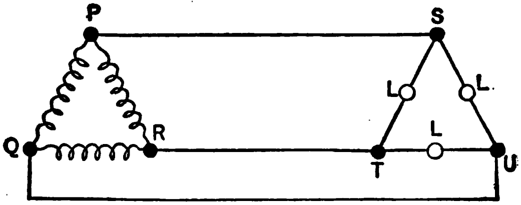


FIG. 502
3-PHASE DELTA CONNECTION

The three wires of a three phase system each act as a main wire, and a return wire for one of the others at the same time. The actual current in the wire is the difference of the two currents: in and outgoing.

If the same three phase armature is connected first as a Y and then as a Δ winding these differences will be noticed.

The Y armature will give the higher voltage and have less current capacity. The Δ will give a lower voltage and have greater current capacity. Power that can be drawn from each is the same.

Transformers and other apparatus are wound two, and three phase, and also Y and Δ, for use with the correspondingly wound alternator.

By a peculiar connection of coils, rotary converters are wound for six phase currents; it having been discovered that it is possible to do so with the result of increased output for a given sized machine.

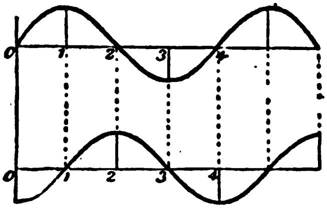


FIG. 503
WAVES IN QUADRATURE

Two, three and six phase machinery is often grouped under name of polyphase.

Waves in quadrature.—Fig. 498 shows waves in phase. In Fig. 503 are shown waves in quadrature, that is the angle of lead is 90° which is a quarter of a circle. When the angle of lag, or lead is 180° the waves are said to be in opposition. This is illustrated in Fig. 504

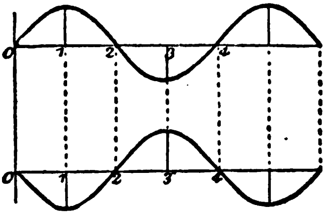


FIG. 504
WAVES IN OPPOSITION

QUESTIONS AND ANSWERS.

795. What is the leading characteristic of the direct current?

Ans. It travels in the same direction of pressure.

796. What is the tendency of the current generated in all dynamos?

Ans. It is alternating in voltage or pressure.

797. Explain the meaning of the term alternating as used in this connection.

Ans. The current starts at a value of zero, rises to a maximum of polarity, descends to a value of zero again, and changing in direction of pressure, rises to a maximum of opposite polarity, from whence it drops to zero again.

798. How then is direct current produced from this alternating current?

Ans. By means of the commutator and brushes on the direct current generator.

799. What is the leading characteristic of the alternating current?

Ans. Its voltage is continually changing at regular intervals from zero to maximum in the direction of opposite polarity.

800. How is this action best represented?

Ans. By wave curves drawn above and below a horizontal line representing zero.

801. In what manner does the action of the alternating current affect the circuit through which it travels?

Ans. The whole circuit passes simultaneously through voltage values of the cycle represented by the wave curve.

802. What is meant by the frequency of an alternating current?

Ans. The number of waves or cycles per second.

803. What does a frequency of 60 mean?

Ans. It means that the voltage values pass through a complete cycle in one sixtieth of a second, that is 60 cycles per second.

804. What is meant by alternations?

Ans. The number of reversals per minute in the direction of pressure.

805. How many alternations would there be in a current having a frequency of 60?

Ans. 7,200.

806. What is meant by a "period?"

Ans. The time in seconds or fractions of a second required to pass through a complete cycle.

807. What is meant by current wave?

Ans. It means the actual values of the current as shown by the volt-meter and ammeter.

808. Do these equal the values of the theoretical wave curve?

Ans. They do not, reaching about 70 per cent.

809. Why is this?

Ans. It is due to the influence of the iron magnetic circuit caused by the connections of induction motors, arc lamps, and other electrical apparatus.

810. What is meant by effective current?

Ans. The voltage and volume as shown by the voltmeter and ammeter.

811. In what respect is the maximum voltage as shown by the calculated wave curve useful?

Ans. It is useful in testing insulating materials.

812. What is meant by phase in electric practice?

Ans. It denotes the relative position of a current wave, with respect to the wave of electro-motive force producing it.

813. When is a current in phase?

Ans. When the two waves just mentioned start at zero and reach their maximum values at the same instant.

814. What is meant by lag?

Ans. When the current wave lags behind the voltage wave.

815. What is meant by lead?

Ans. When the current wave is ahead of, or leads the voltage wave.

816. What is the meaning of two and three phase currents?

Ans. When the winding of the armature is such that two or three electro-motive forces in quadrature with each other are simultaneously produced by the generator the currents thus produced may be distributed over four or six conductors, a pair for each current.

817. Is it necessary to have a pair of conductors for each current in two and three phase current work?

Ans. No. By means of the Y winding it is possible to distribute the current over three wires, each wire acting as a main, and return wire for one of the others.

SWITCHBOARDS.

Switchboards are made up of panels of slate on a frame of angle iron. Each panel is designed for certain work so that a description of the different kinds of panels is sufficient.

The first board to consider is the D. C. outgoing line board, served from D. C. generators.

D. C. Generator Panels.

Fig. 547 shows three generator panels, each of which is regularly equipped, from a capacity of 250 to 6,500 amperes with

1 Carbon break or magnetic blow-out circuit breaker, with telltale.

1 Illuminated dial ammeter with shunt.

1 Hand wheel and chain for operating rheostat.

1 Receptacle for voltmeter plug

1 S. P.-S. T. field switch.*

1 S. P.-S. T. main switch.

1 Recording Watt-hour meter.

A rear view of these panels is shown in Fig. 552.

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*S. T. means single throw.

D. T. means double throw, i. e., the switch has two sets of clips and can be thrown into either of them.

S. P. means single pole.

D. P. means double pole, i. e., opens both sides of circuit

T. P. means triple pole, i. e., opens every conductor of a 3-phase system.

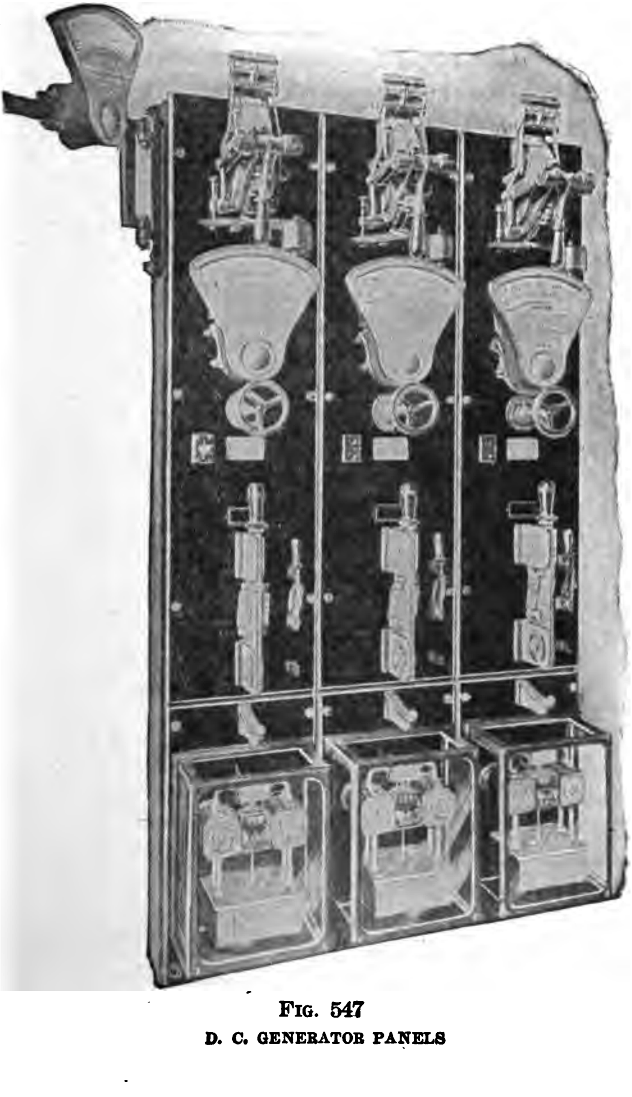


Fig. 547

D. C. GENERATOR PANELS

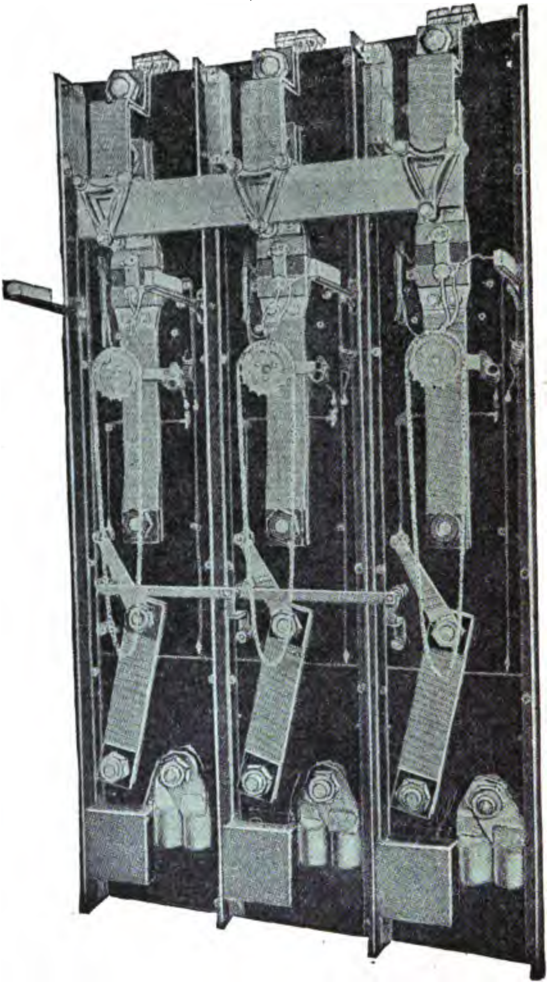


Fig. 548
REAR VIEW OF FIG. 547

The best practice puts a main switch at the machine, so that the cables from machines to board may be cut off from generator. It is also good practice to run the equalizer cable along in ducts from machine to machine without carrying it to the board.

This equalizer connects the junctions of series field and brush on all machines as shown in Fig. 549; the shunt coils being omitted to simplify diagram.

It is best to place the main switch and equalizer switch on a pedestal panel as shown in Fig. 550 for moderate capacity and in Fig. 551 for 4,000 ampere (and larger) machines. The upper switch being the main switch. The rear view of these large capacity pedestals is shown in Fig. 556.

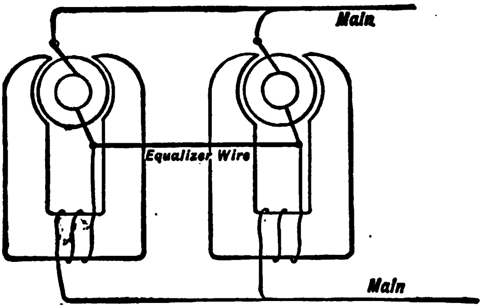


FIG. 549
EQUALIZER

A better view of the 4,000 ampere toggle operated main switch is given in Fig. 553. The quick-break S. P.-S. T. switch is illustrated in Fig. 554.

The field switch, Fig. 555, has a carbon break. Just before the switch opens it makes contact with an extra clip which puts a resistance on as a shunt around the field coils.

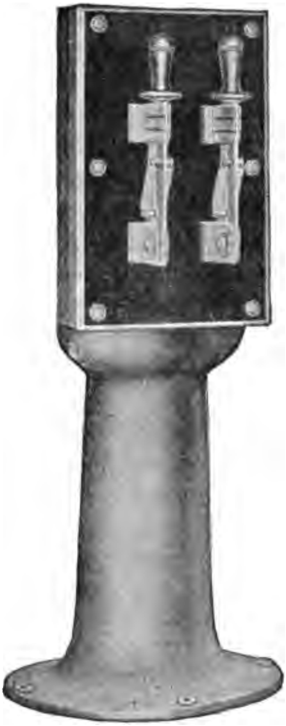


Fig. 550.

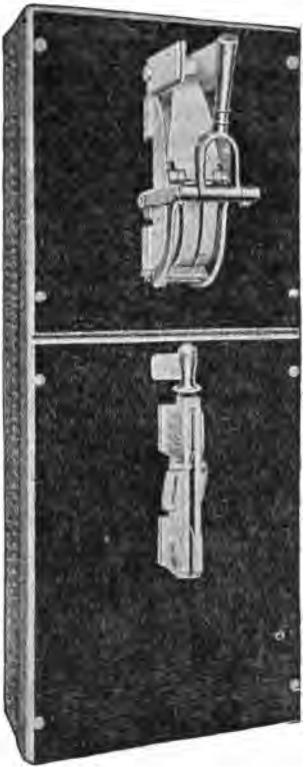


Fig. 551

Fig. 550

PEDESTAL PANEL FOR MAIN AND EQUALIZER SWITCHES
SMALL CAPACITY

Fig. 551

MAIN AND EQUALIZER SWITCHES FOR LARGE CAPACITY

If this were not done the fields would act like a kicking, or spark coil and their insulation be damaged.

In Fig. 556 is seen the diagram of the panel shown in Figs. 557 and 558 when capacity is 800 K. W. or under.

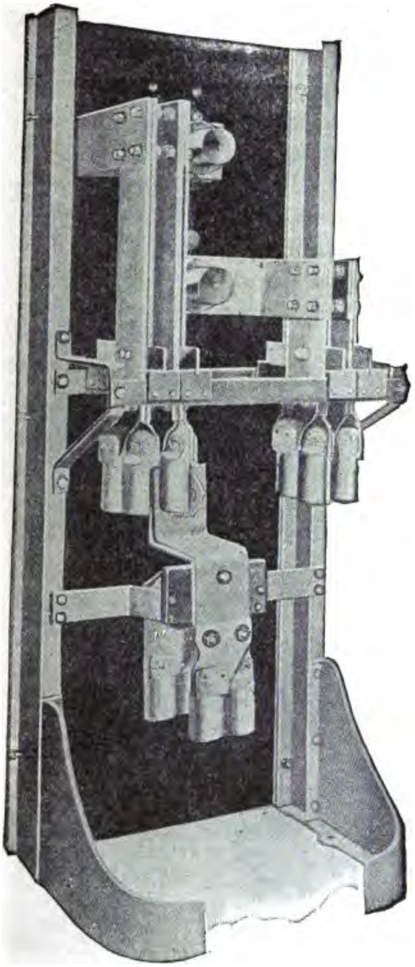


Fig. 552

REAR VIEW OF FIG. 551

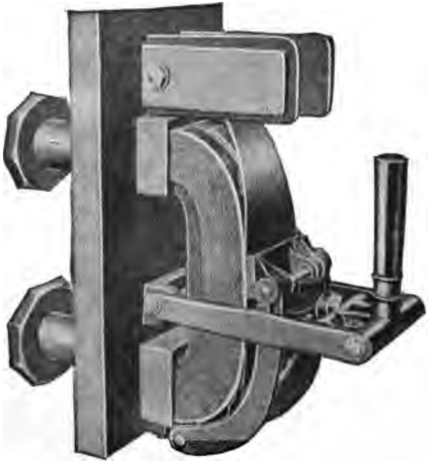


FIG. 553

4,000 AMPERE TOGGLE OPERATED SWITCH. LAMINATED MAIN CONTACT, CARBON SECONDARY CONTACT WITH MAGNETIC BLOWOUT.

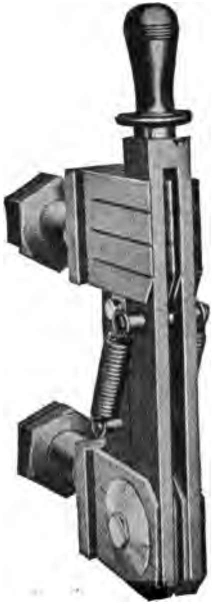


FIG. 554

3,600 AMPERE QUICK BREAK SWITCH.

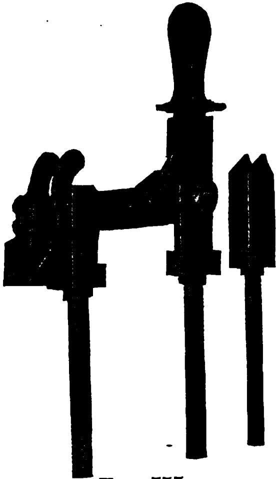


FIG. 555

FIELD DISCHARGE SWITCH.

Fig. 557 shows the same panel when capacity is larger. The panel at left is for 1,000 and 1,200 K. W., the next for 1,500 K. W. and over. The cuts on right side show the back and side view of the 1,500 K. W. panel.

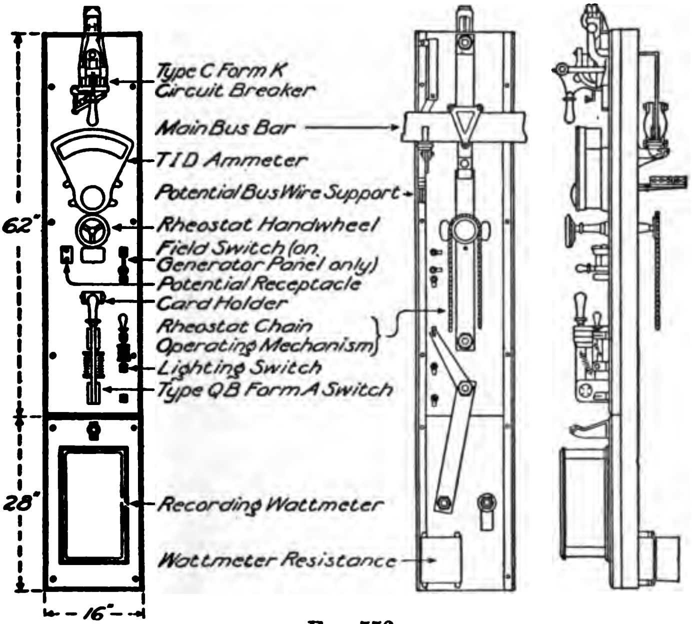


FIG. 556

CONSTRUCTION OF FIG. 547 FOR SMALL CAPACITY

The scheme of electrical connections for panel of Fig. 547 is shown in Fig. 558.

D. C. Feeder Panels.

A set of feeder panels for one feeder each is shown in Figs. 559 and 560, a panel for two feeders with separate switches and one ammeter reading sum of both currents is

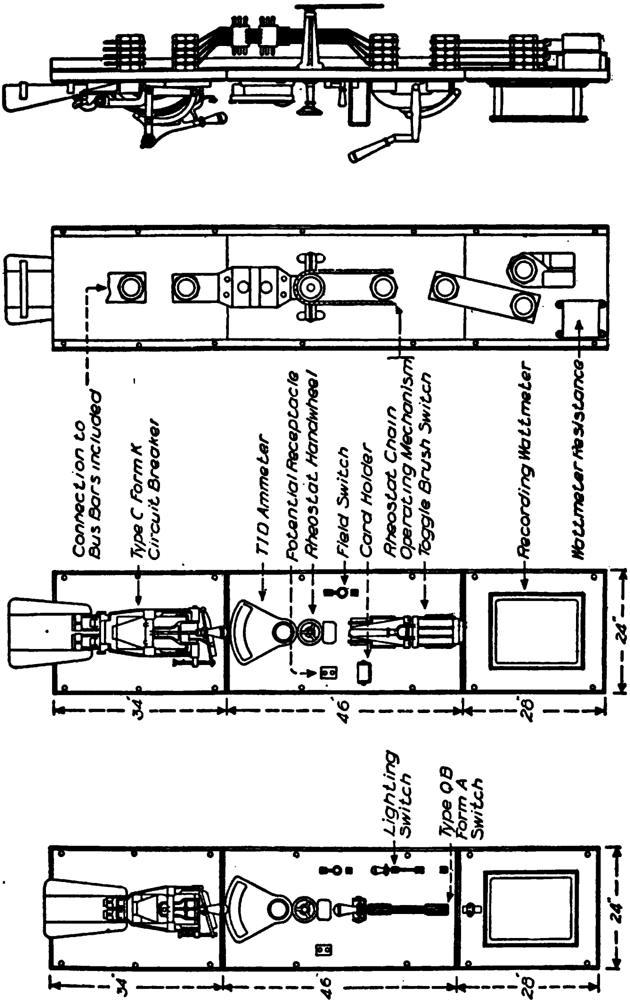


FIG. 557
CONSTRUCTION OF FIG. 547 FOR LARGE CAPACITY

shown in Fig. 561, while Fig. 562 has an instrument and switch for each circuit.

Fig. 563 gives the diagram of these feeder panels and Fig. 564 gives the electrical connections.

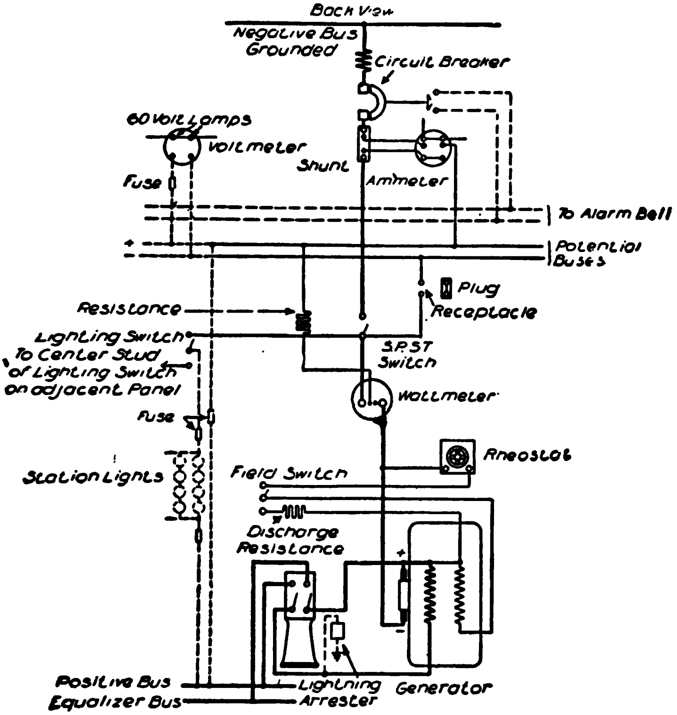


FIG. 558

D. C. GENERATOR PANELS

With panels as described the way to throw a generator in parallel with other generators already running, the following procedure should be followed:

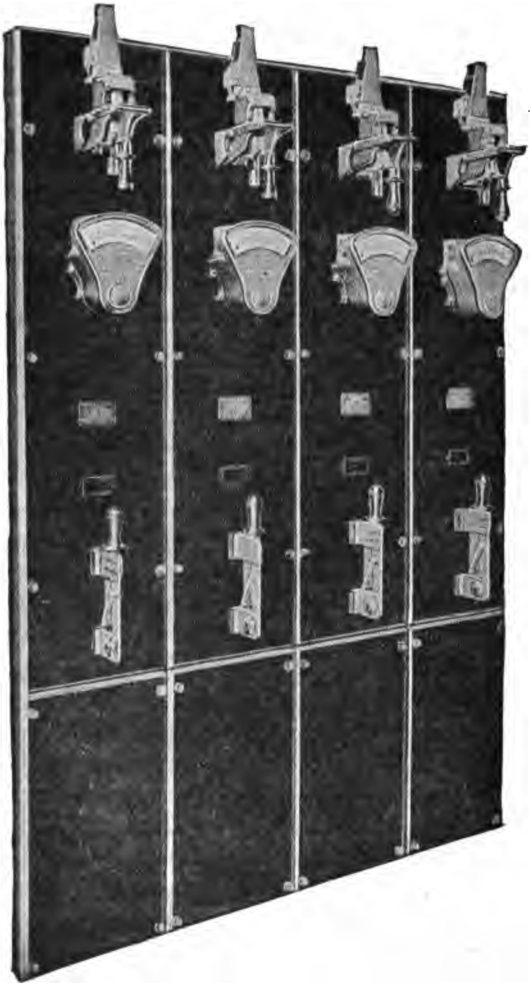


Fig. 559
D. C. FEEDER PANELS

First—Close main and equalizer switches (on pedestal or panel near machine).

Second—Close field switch (on panel).

Third—Close circuit breaker.

Fourth—Insert potential plug in receptacle and regulate voltage.

Fifth—When the proper voltage is obtained, close the other main switch (on panel).

All the above applies to the distribution of the output of rotary converters, but as they have some peculiarities they will be considered later.

A. C. Generator Panel.

The panel in Fig. 565 contains:

1 Horizontal edgewise balanced three-phase indicating wattmeter, arranged for reading both the kilowatts output and the wattless component.

1 Horizontal edgewise ammeter.

1 Horizontal edgewise volt-meter.

1 Balanced three-phase induction recording wattmeter.

1 D. P. D. T. potential reversing switch for the indicating wattmeter.

1 Four-point receptacle for synchronizing connections.

1 Hand-wheel and chain operating mechanism for field rheostat.

1 S. P. S. T. carbon break field switch with discharge clips.

1 D. P. D. T. engine governor control switch.

1 T. P. S. T. oil switch.

1 Current transformer for instruments.

2 Potential transformers for instruments.

The functions of the instruments are to indicate the current, voltage and kilowatts output of the generator, and the wattless component of the output. For indicating the

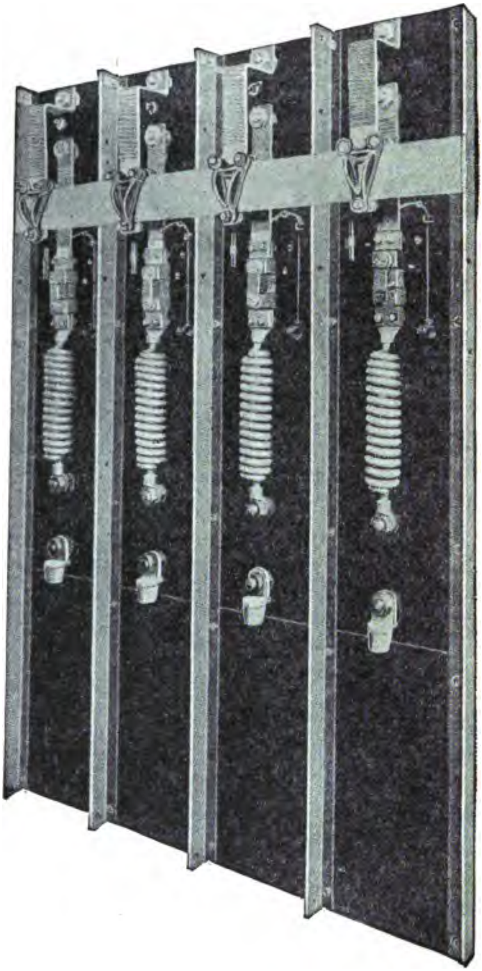


FIG. 560
REAR VIEW OF FIG. 559

wattless component, the potential coil of the indicating wattmeter is wired to the potential reversing switch, which is normally held by a spring so as to connect the instrument up as a wattmeter. By throwing the switch against the spring into the other position the potential coil is reversed, and the instrument reads the wattless compotent, giving a ready means of detecting any currents flowing between the alternators which are operating in parallel.

The engine governor switch is to operate the motor which temporarily controls the governor on engine, or turbine when their speeds are being altered to bring two alternators into synchronism, or adjusting the division of load when operating in parallel.

The generator oil switch has no automatic overload release, as it is important to keep the generator in service during heavy short circuits caused by trouble on the transmission lines. When such short circuits occur, the generators are immediately relieved by the opening of the automatic line switches.

The diagrams for connecting up generator panels according as transformers are, or are not used will be found in Figs. 566 and 567.

A. C. Outgoing Panel.—The panel on left of Fig. 568 contains:

3 Horizontal edgewise ammeters.
1 T. P. S. T. oil switch, with overload release.
3 Current transformers.

Three ammeters—one for each phase—are furnished for each line, to facilitate the detection of unbalancing due to open circuits or leakage. With balanced loads, the ammeter pointers should show equal deflections under normal conditions. As the ammeters are arranged in a perpendicu-

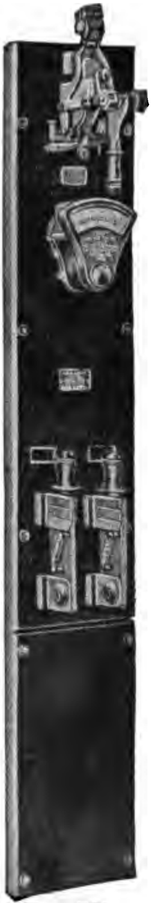


Fig. 561

TWO FEEDER D. C. PANEL

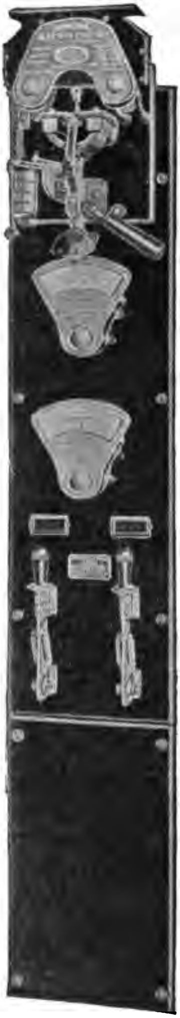


Fig. 562

1,200 D. C. AMPERE, RAILWAY FEEDER PANEL FOR TWO CIRCUITS

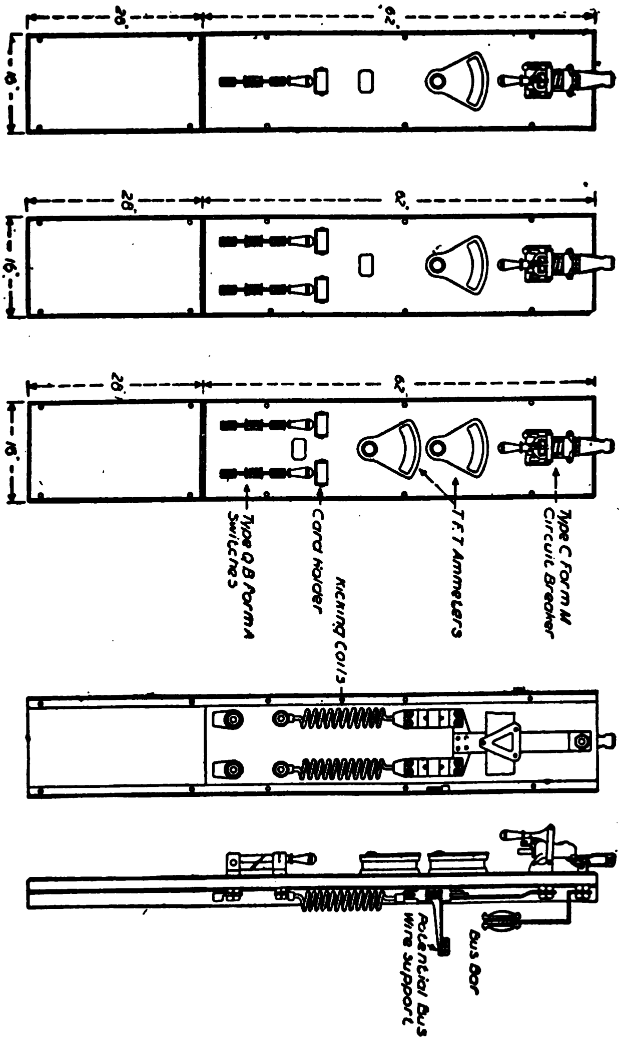


Fig. 563
CONSTRUCTION OF FIGS. 559 AND 562

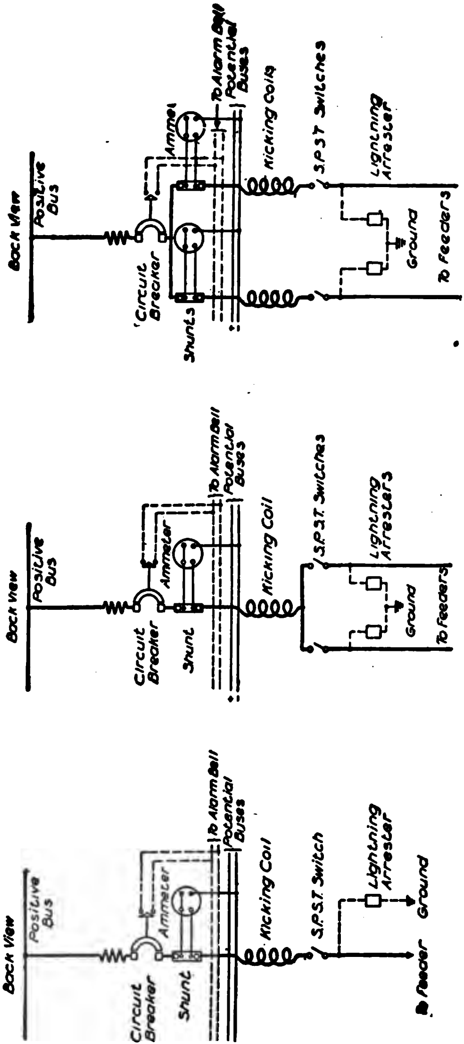


FIG. 564
THREE STYLES OF D. C. FEEDER PANELS

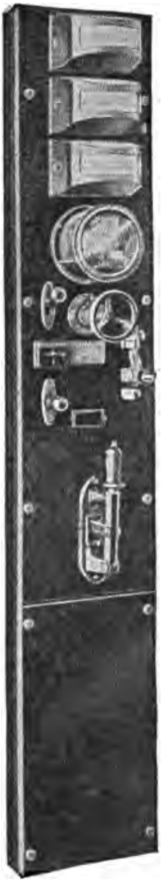


Fig. 565

A. C. GENERATOR PANEL

lar row any variation in the deflection of the pointers is readily detected.

The current transformers serve to operate the ammeters and the automatic release on oil switches.

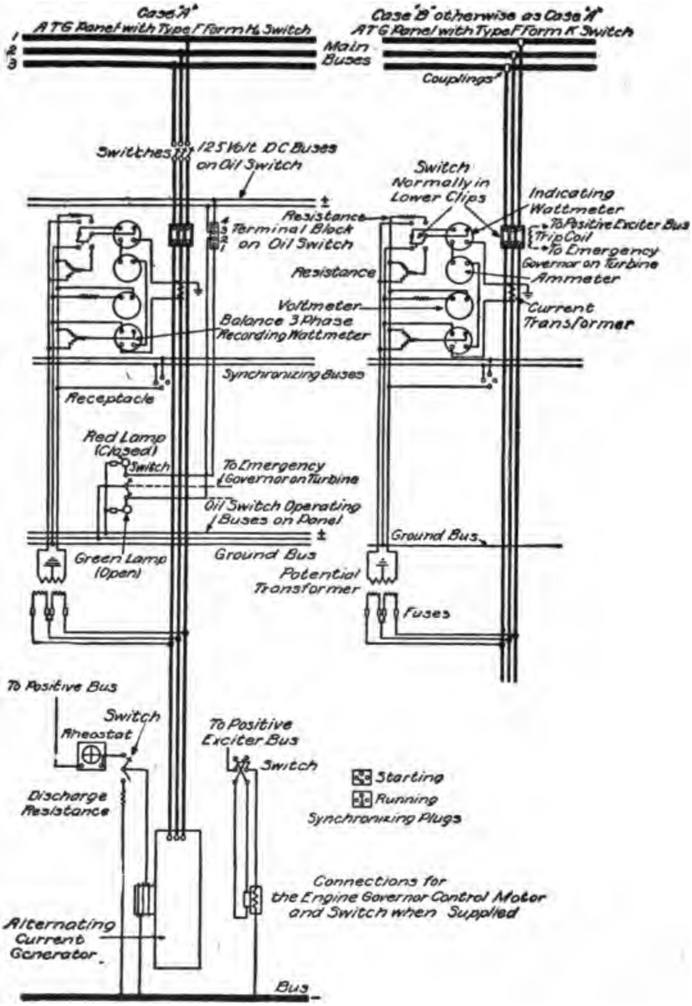

Case "A"
A T G Panel with Type F Form H3 Switch
1
2
3
Main Buses
Case "B" otherwise as Case "A"
A T G Panel with Type F Form K Switch
Couplings
Switches
125 Volt DC Buses on Oil Switch
Switch Normally in Lower Clips
Indicating Wattmeter
Resistance
4
3
2
1
Terminal Block on Oil Switch
To Positive Exciter Bus
Trip Coil
To Emergency Governor on Turbine
Resistance
Ammeter
Voltmeter
Current Transformer
Balance 3 Phase Recording Wattmeter
Synchronizing Buses
Receptacle
Red Lamp (Closed)
Switch
To Emergency Governor on Turbine
Oil Switch Operating Buses on Panel
Ground Bus
Ground Bus
Green Lamp (Open)
Potential Transformer
Fuses
To Positive Bus
Switch
Rheostat
To Positive Exciter Bus
Switch
Starting
Running
Synchronizing Plugs
Discharge Resistance
Connections for the Engine Governor Control Motor and Switch when Supplied
Alternating Current Generator
Bus

FIG. 566

A. C. GENERATOR PANEL WITHOUT STEP-UP TRANSFORMERS

The panel on right of Fig. 568 has but one ammeter and merely has the handle for operating the oil switch. The actual switch being in a brick compartment at rear of panel. The overload relay (3-pole) which trips the oil switch is at base of panel.

Fig. 569 gives the electrical connections of panels in Fig. 568.

The swinging bracket of Fig. 570 contains a synchronism indicator, two lamps for synchronizing (practically a duplicate set of synchronizers) and a voltmeter for the station exciter generator.*

To use the synchronism indicator put one plug in on panel of a generator which is running, and the other plug in the panel of the generator which is starting.

Fig. 571 shows a complete switchboard of one generator panel in center, a panel for one outgoing line on the right, an exciter panel on left, with the swinging bracket on extreme left.

Such a switchboard would be extended towards the right indefinitely, as more lines were put on the station, by the addition of more outgoing line panels.

Exciter Panel.—Each exciter panel is equipped with:

1 Thomson feeder type ammeter.

1 Hand-wheel for operating rheostat.

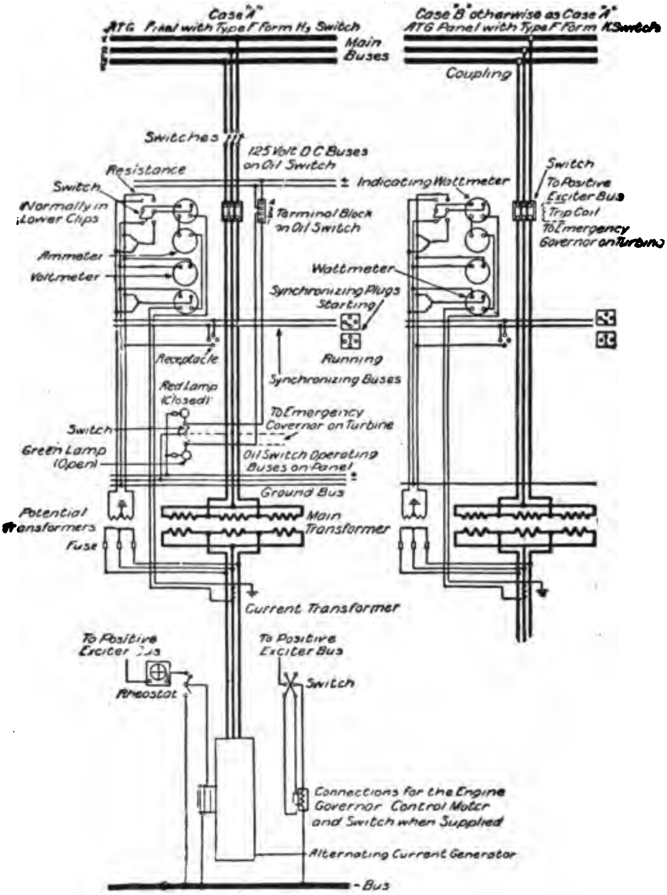
1 Two-point potential receptacle connected to voltmeter.

1 S. P. S. T. positive lever switch, with fuse mounted back of panel.

One Exciter Panel in every switchboard is furnished with the following additional switches: (as in Fig. 572.)

---

*D. C. Generator furnishing current for field of alternator.



ALTERNATING CURRENT GENERATOR PANEL FOR GENERATOR WITH STEP-UP TRANSFORMER

FIG. 567

A. C. GENERATOR PANEL FOR GENERATOR WITH STEP-UP TRANSFORMER

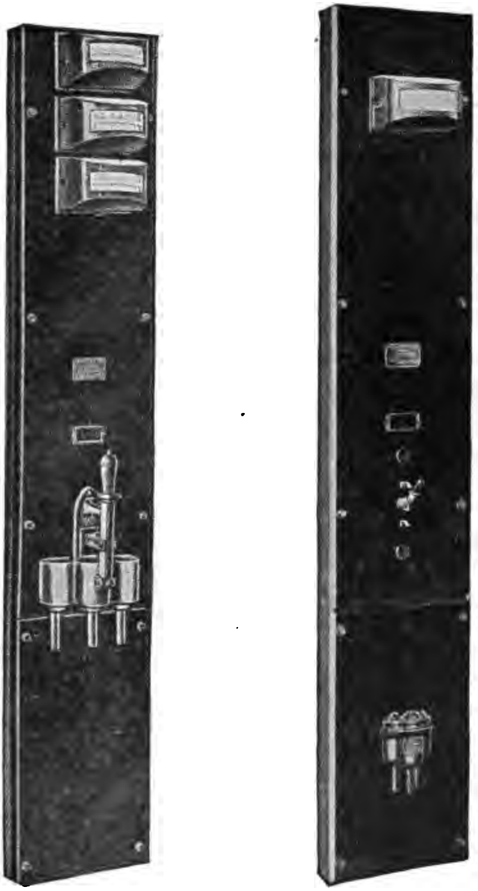


Fig. 568

A. C. OUTGOING LINE PANELS

2 S. P. S. T. lever switches, with fuses back of panel, for the control of station lighting and auxiliary circuits.

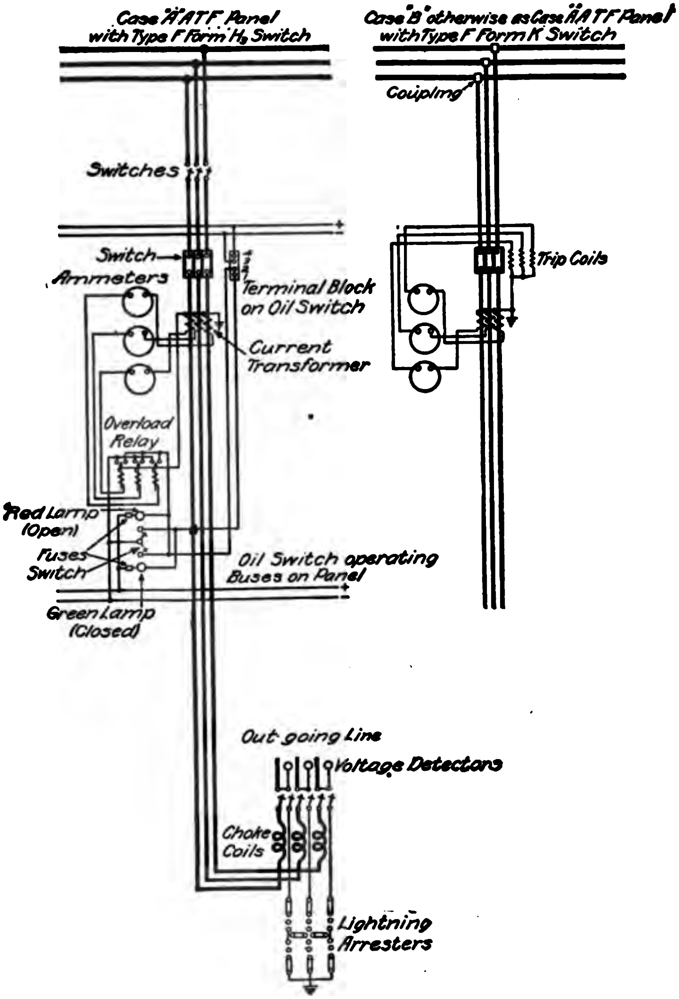


FIG. 569

A. C. OUTGOING LINE PANEL

On the frame of each exciter there are required the following switches, mounted on a common slate base:

1 S. P. S. T. negative lever switch.

1 S. P. S. T. lever switch for equalizing.

The exciter panels are designed single pole, *i. e.,* only the positive leads of the generators are connected to the switch-board panels and only the positive bus-bar is mounted back of them. The negative and equalizer leads are connected through their switches to the negative and equalizer bus-bars, which are placed under the floor near the exciters. With the bus-bars of opposite polarity so widely separated there is practically no chance of short circuit of the exciter connections. The positive field leads of the alternators are carried to the panels, while the negative field leads are permanently connected to the negative exciter bus-bar.

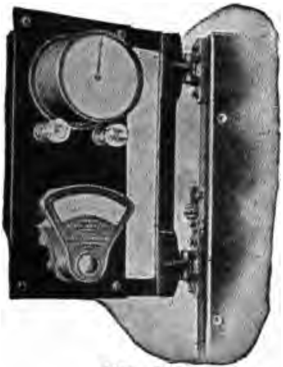


FIG. 570

SYNCHRONISM INDICATOR AND EXCITER VOLTMETER ON SWINGING BRACKET

Fig. 573 will give the electrical connections of an exciter panel.

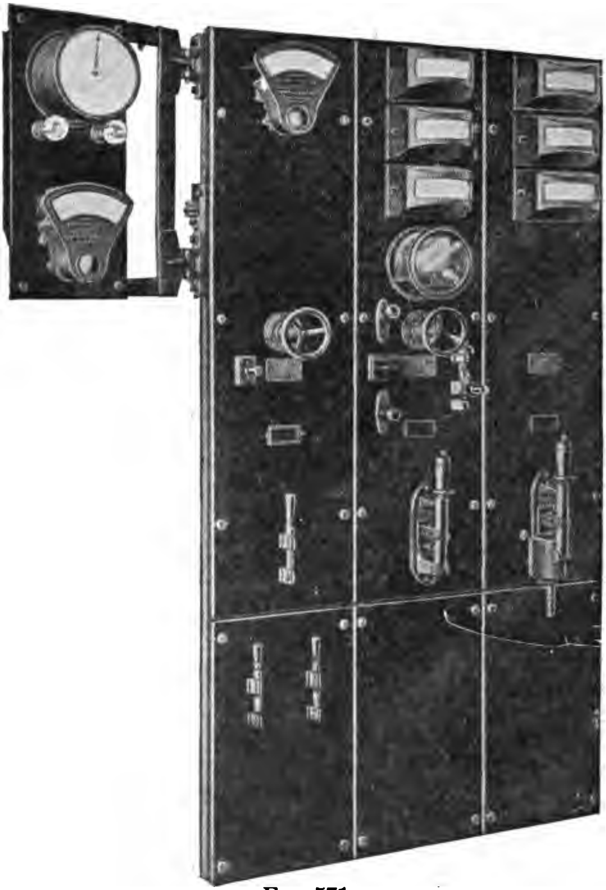


FIG. 571

MAIN STATION SWITCHBOARD FOR ONE A. C. GENERATOR AND ONE OUTGOING LINE

The blower motors running the blowers which cool transformers are of the 3-phase induction type, or D. C. shunt motors.

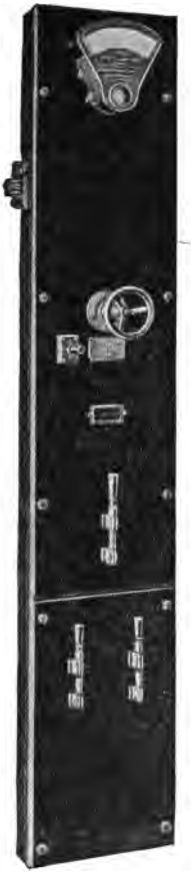


FIG. 572

EXCITER PANEL AUXILIARY LIGHTING SWITCHES ON SUB-BASE

The D. C. motors are started by the regular starting box, Fig 574.

The current to an induction motor is controlled by a switch like Fig. 575. if from auxiliary low voltage buses,

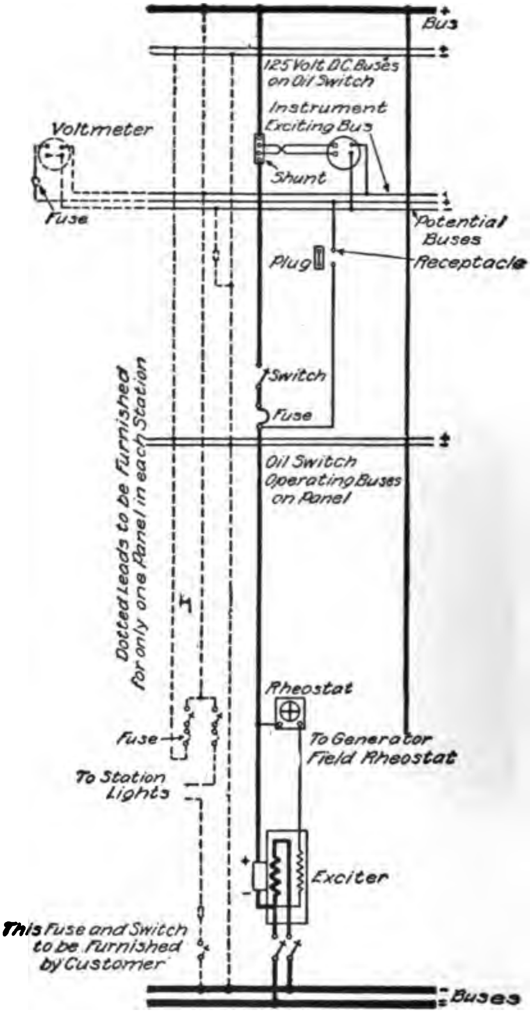

+ Bus
±
125 Volt D.C. Buses on Oil Switch
Instrument Exciting Bus
Voltmeter
Shunt
Fuse
±
Potential Buses
Plug
Receptacle
Switch
Fuse
±
Oil Switch Operating Buses on Panel
Dotted Leads to be Furnished for only one Panel in each Station
Rheostat
To Generator Field Rheostat
Fuse
To Station Lights
+
-
Exciter
This Fuse and Switch to be Furnished by Customer
± Buses

FIG. 573
EXCITER PANEL

or from an oil switch on a panel like Fig. 576, if full station voltage is used.

The actual starting is done by a switch as in Fig. 577, which is between secondaries of transformers or reactance coils and the induction motor.

Fig. 578 shows connections of an induction motor to main buses, using an oil switch and a starting switch.

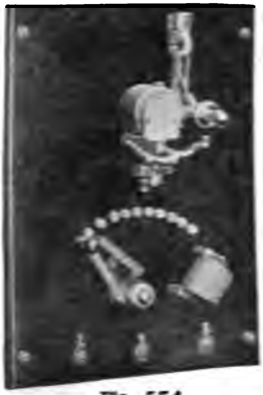


Fig. 574

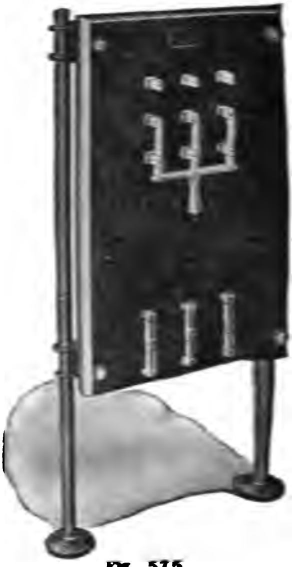


Fig. 575

FIG. 574

STARTING PANEL FOR D. C. BLOWER SET

FIG. 575

MAIN SWITCH PANEL FOR A. C. BLOWER SET

The operation of several sub-stations on a single line is generally recognized as good practice.

To insure continuity of service in the event of line trouble, it is expedient to sectionalize the line at every sub-

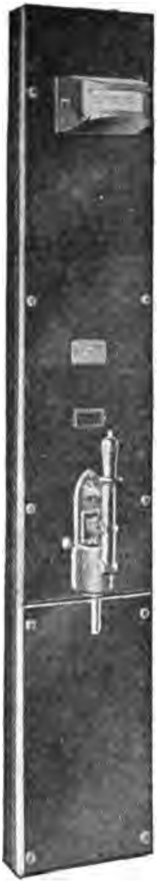


Fig. 576

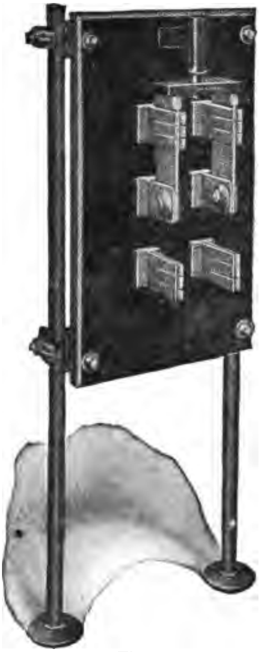


Fig. 577

Fig. 576

OIL SWITCH A. C. PANEL FOR INCOMING LINE

MOTOR DRIVING EXCITER OR A. C. SIDE OF ROTARY

Fig. 577

INDUCTION MOTOR OR ROTARY STARTING PANEL station that is located at an intermediate point of the line. This sectionalizing is accomplished at each intermediate station by carrying the incoming line to the bus-bars through the air brake disconnecting switches which are installed in connection with the arresters, and by carrying the outgoing line through an oil switch. In case of line trouble, this arrangement allows all sections of the line between the generating station, and any section on which the trouble occurs to be operated continuously. The power is automatically cut off from the section in trouble by an oil switch in the outgoing line panel equipment of the sub-station at the generating station end of the section, so that the air brake disconnecting switches in the sub-station at the other end of the section need never be opened under load.

When duplicate transmission lines are used, two incoming line panels and two outgoing line panels are recommended for each intermediate sub-station. The installation of these individual panels facilitates the disconnection of either line of any section and the continuance of the service over the other line of the section without any interruption.

Arc Switchboards.—Fig. 579 shows a general view of the Thomson-Houston plug switchboard. A rear view of the same board is given in Fig. 580.

In a standard panel the number of horizontal rows of holes equals one more than the number of generators. The vertical holes are always twice the number of generators. The positive leads of the generators are attached to the binding posts on the left-hand ends of the horizontal conductors. The negative leads are connected to the corresponding binding posts at the right-hand end of the board.

The positive line wires are connected to the vertical straps

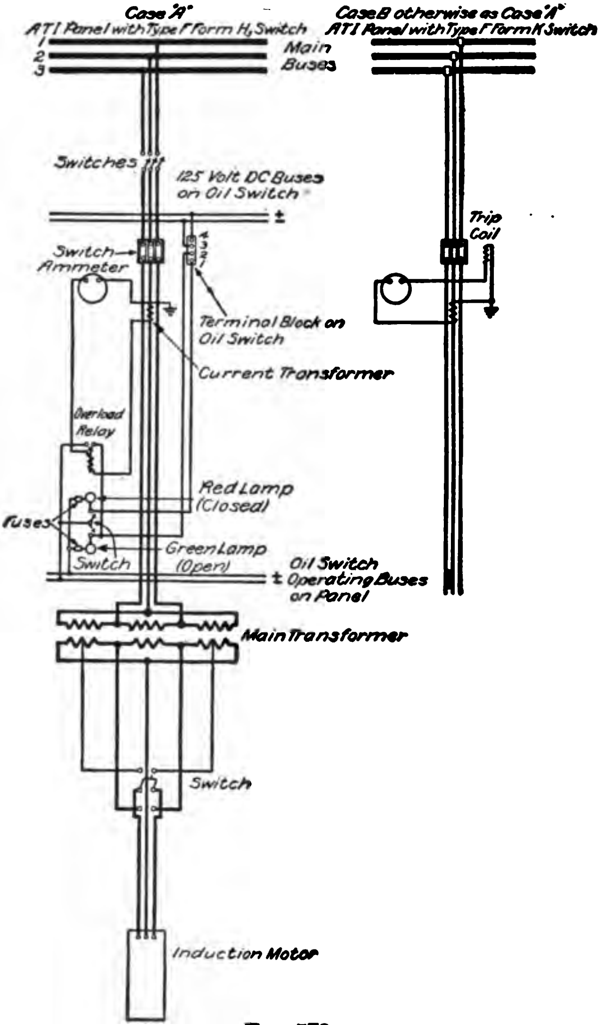

Case "A"
ATI Panel with Type F Form H, Switch
Case B otherwise as Case "A"
ATI Panel with Type F Form K Switch
1
2
3
Main Buses
Switches
125 Volt DC Buses on Oil Switch
±
Trip Coil
Switch Ammeter
4
3
2
1
Terminal Block on Oil Switch
Current Transformer
Overload Relay
Red Lamp (Closed)
Fuses
Green Lamp (Open)
Switch
Oil Switch Operating Buses on Panel
±
Main Transformer
Switch
Induction Motor

FIG. 578

INDUCTION MOTOR PANEL

on the left, and the negative wires to the similar straps on the right of the center panel.

If a switchboard plug be inserted in any of the holes of the board, it puts the corresponding generator lead and the line wire in electrical connection, but as the positive line wires are back of the positive generator leads only, it is not possible to reverse the connection of the line and the generator accidentally, though any other combinations of lines and generators can be made readily and quickly.

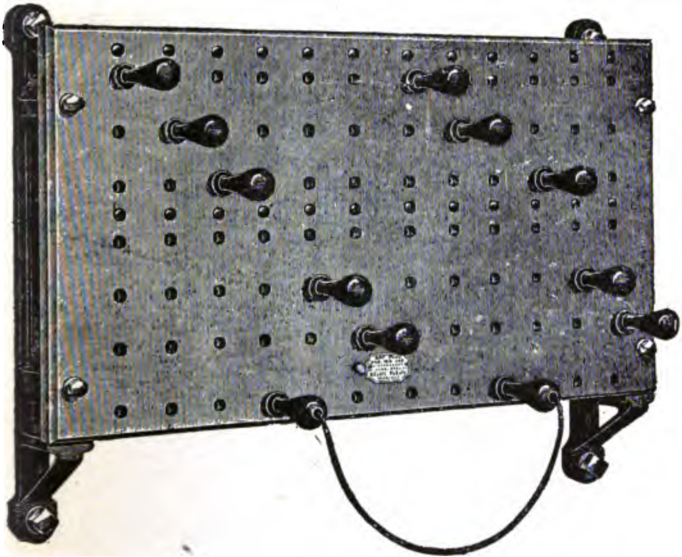


FIG. 579

The holes of the lower horizontal rows have bushings connected with the vertical straps only. Plugs connected in pairs by flexible cable and inserted in the holes put the corresponding vertical straps in connection as needed, and normally independent lines may be connected when one generator is required to supply several circuits.

Lines and generator leads may be transferred, while running, by the use of these cables, without shutting down machines or extinguishing lamps.

The standard boards are arranged for an equal number of generators and circuits, but special boards for any ratio of circuits to generators can be built.

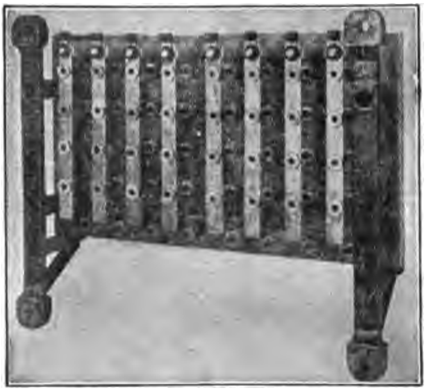


Fig. 580

As it is sometimes convenient, even in small plants, to interchange lines and generators without shutting down machines, a special transfer cable with plugs has been devised. This serves the same purpose as the regular transfer cable, but the plugs may be used in any of the holes of the switchboard, as they are insulated, except at the tip, and when inserted connect with the line strips only.

The transfer of circuits from one generator to another gives trouble to dynamo tenders who are not familiar with the operation of these plug switchboards. Fig. 581 illus-

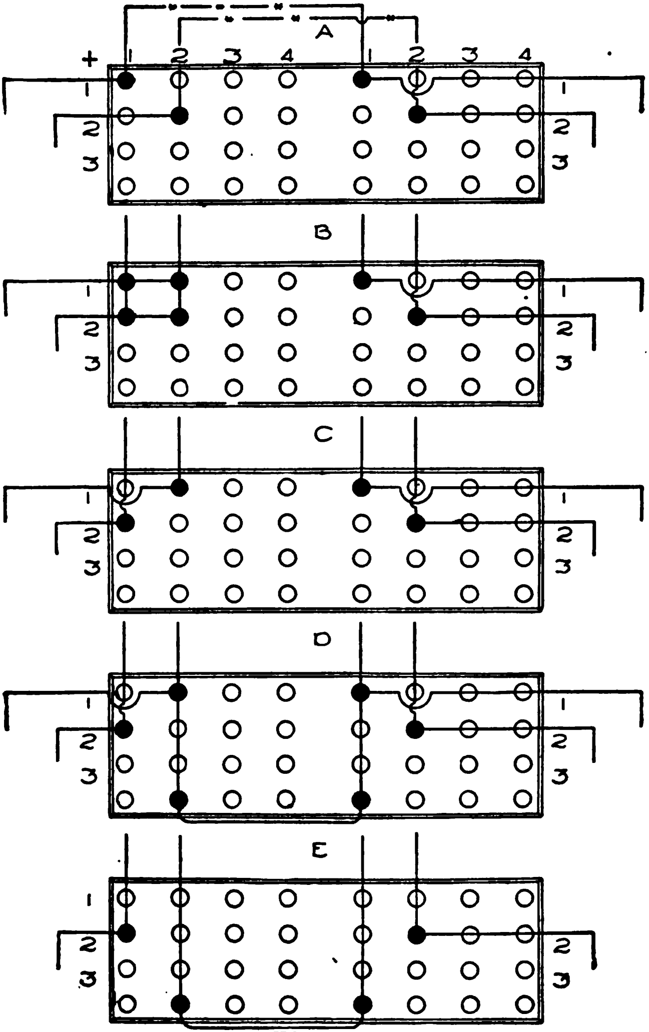


Fig. 581

trates the successive steps for transferring the lamps of two independent circuits from two generators to one without extinguishing the lamps on either circuit.

This process is a very simple example of switchboard manipulation, but illustrates the method used for all combinations.

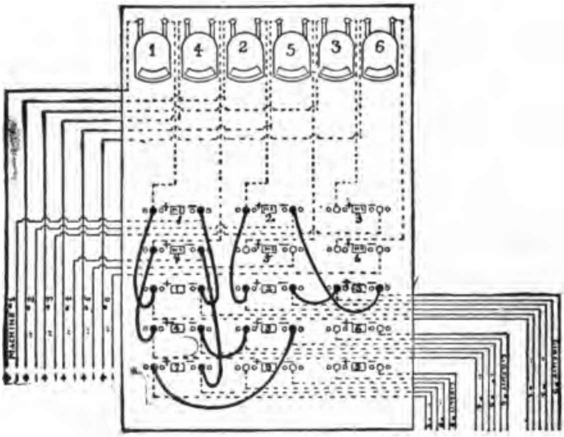


FIG. 582

The location of plugs is shown by the black circles, which indicate that the corresponding bars of the horizontal and vertical rows are connected.

Circuits No. 1 and No. 2, running independently from generators No. 1 and No. 2, respectively, are to be transferred to run in series on generator No. 2.

In A, Fig. 581, are two circuits running independently. In B the positive sides of both generators and circuits are connected by the insertion of additional plugs.

At C both generators and circuits are in series.

Next insert plugs and cables as shown in D. Then withdraw plugs on row corresponding to generator No. 1, and the circuits No. 1 and No. 2 are in series on machine No. 2, and machine No. 1 is disconnected as at E.

Similar transfers can be made between any two circuits or machines, and by a continuation of the process additional circuits can be thrown in the same machine. The transfer of the two circuits to independent generators is accomplished by reversing the process illustrated.

Fig. 582 shows the wiring and connections of the Western Electric Co.'s series arc switchboard. At the top of the board are mounted six ammeters, one being connected in the circuit of each machine. On the lower part of the board are a number of holes, under which, on the back of the board, are mounted spring jacks to which the circuit and machine terminals are connected. For making connections between dynamos and circuits, flexible cables terminating at each end in a plug, are used; these are commonly called "jumpers." The board shown has a capacity of six machines and nine circuits, and with the connections as shown, machine 1 is furnishing current to circuit 1, machine 2 is furnishing current to circuits 2 and 3, and machine 4 is furnishing current to circuits 4, 5 and 7. In connecting together arc dynamos and circuits the positive of the machine (or that terminal from which the current is flowing) is connected to the positive of the circuit (the terminal into which the current is flowing). Likewise the negative of the machine is connected to the negative of the circuit. Where more than one circuit is to be operated from one dynamo, the negative of the first circuit is connected to the positive of the second. At each side of the name plate (at 3, for instance) there are three holes. The large hole is used for the permanent connection, while the smaller holes are used for transferring circuits, without shutting down the dynamo. Smaller cables and plugs are used for transferring. If it is desired to cut off circuit 5 from machine 4, a plug is inserted in one of the small holes at the right of 4, the other plug being inserted in one of the holes at the left of 7. Circuit 5 would now be short-circuited, and the plug in the + of 5 can now be transferred to the permanent connection in the + of 7, and the cords running to 5 removed. If it is desired to cut in a circuit, say circuit 6 onto machine 2, insert a cord between the — of circuit 2 and the + of 6 and another between the — of 6 and the + of 3. Now pull the plug on the cord connecting the — of 2 and the + of 3 and insert the permanent connections. In cutting in circuits, if they contain a great number of lights, a long arc may be drawn when the plug between 2 and 3 is pulled, and it is sometimes advisable to shut down the machine when making a change of this kind.

TRANSFORMERS.

When a current passes through a conductor it creates around it a field of force. If a second wire, or conductor lies parallel to the first during the time that the field of force is being built up, electromotive force will be impressed upon it, and will be of such polarity that the current produced by it will be in a direction opposite to the direction of the original current. The transformer contains two coils of wire insulated from each other.

In Fig. 583 is shown the principle upon which the transformer used in alternating current work operates. Two separate coils of wire are wound on a ring of laminated iron. One of the coils contains a number of turns of fine wire, while the other contains only a few turns of large wire. When an alternating current is sent around the coils of fine wire, generally called the primary, a current will be induced in the coil of heavy wire, or secondary. The amount of current induced in the larger wire will be relatively greater in amperes, and less in potential than that of the fine wire circuit. This ratio is almost entirely dependent upon the relative number of turns existing between the large and the small wires. To illustrate, suppose we had a current of 10 amperes at a pressure of 1,000 volts in the primary, and there were ten times as many turns of wire in the primary coil as in the secondary, then we would get a current of 100 amperes at a pressure of 100 volts in the secondary coil. This same relation would hold true whatever the ratio between the number of turns on the two coils might be. In Fig. 584 is shown a core of iron having on one end a primary coil connected to a battery. On the other end of the core is another coil connected to the ends of which is an incandescent lamp. By making and breaking the battery circuit the lamp may be made to flash

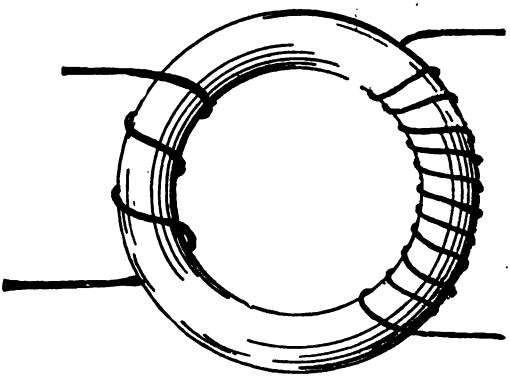


FIG. 583

up, due to the great voltage induced in the secondary coil. This is a good thing to remember when working with a dynamo or motor. Do not quickly break the shunt field connection, as the increased voltage due to the current induced by the field magnet when the circuit is broken is liable to puncture the insulation and necessitate the rewinding of the field coil.

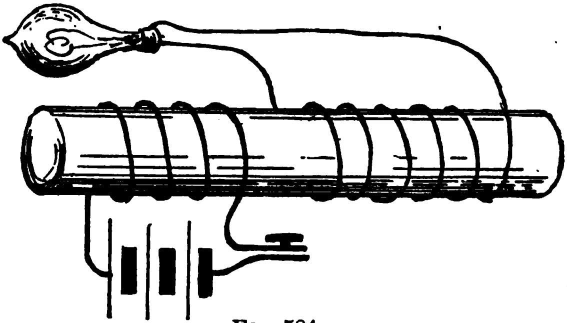


FIG. 584

Referring to Fig. 585, A represents the alternator, B its brushes and D and E the mains to the transformer H. This transformer consists of a core of iron C on which are two windings. The coil P is called the primary, and is connected to the main from alternator. The other coil S is called the secondary, and to it the load is connected.

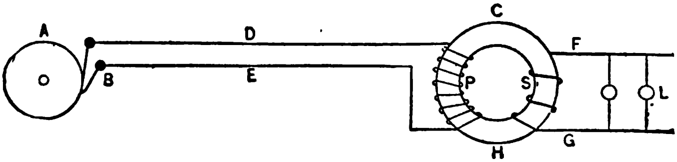


FIG. 585

DIAGRAM OF ALTERNATOR, LINE, TRANSFORMER, AND SECONDARY CIRCUIT

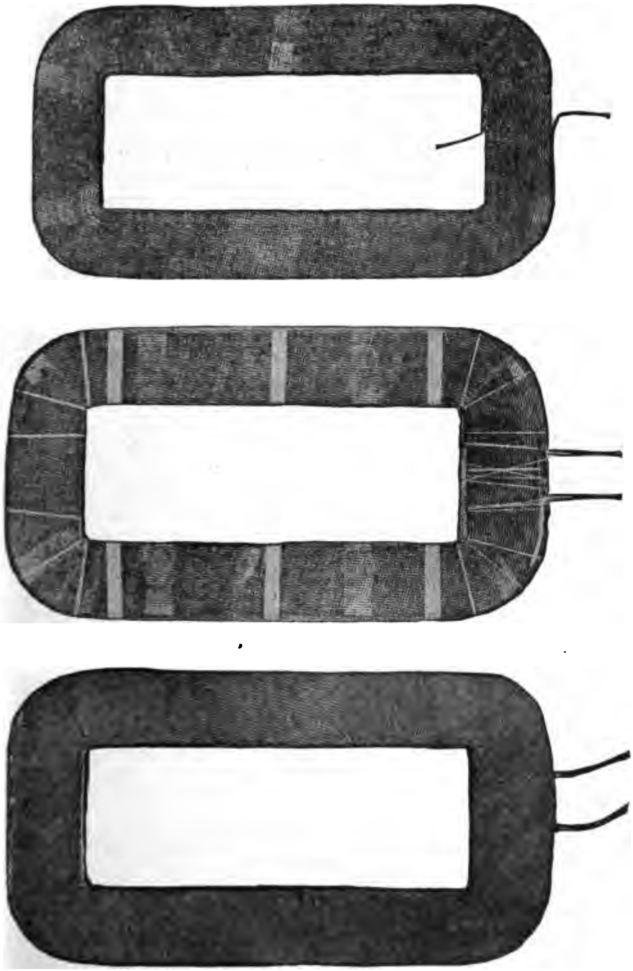


FIG. 586
TRANSFORMER COILS IN WOUND, BOUND AND TAPED STAGES OF COMPLETION

Whatever the voltage of alternator A, that of the secondary circuit F. L. G. will be three-eighths of it because there are eight turns on the primary and three turns on the secondary. The power in the secondary circuit is practically the same (minus the losses) as is given out by the alternator, hence the primary current is low and wire is small. The secondary current is large and the wire is large.

Since one kilowatt can be a combination of a large current and small pressure, or small current and large pressure, it is evident that the transformer simply transfers the power, and transforms the voltage, and indirectly the current.

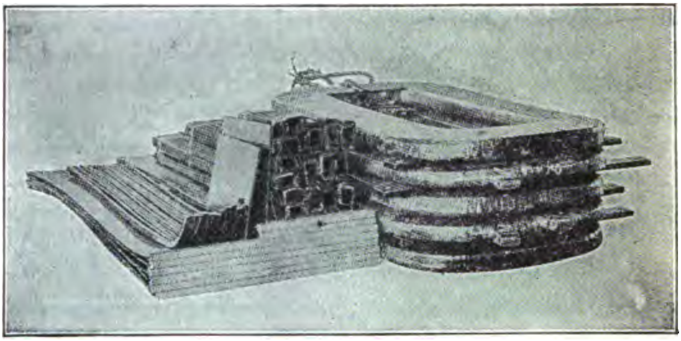


FIG. 587
COILS, AIR DUCTS AND SEPARATORS FOR TRANSFORMER

This transformer (Fig. 585) lowers the voltage and is called a step down transformer.

When the secondary is connected to the alternator, the transformer raises the voltage and is called a step up transformer.

The coils of a transformer must be very well insulated. After winding they are bound, to keep them in shape, and then wound with linen tape, or varnished cambric cloth. Fig. 586 shows a coil in the three stages of completion.

In Fig. 587 is shown a set of completed coils, together with the ventilating ducts and mica barriers sufficient for one leg of a transformer.

Fig. 588 shows the two legs of a transformer, which form its iron core, each over half filled with coils. The coil is made of sheets of soft iron.

Fig. 589 shows the manner in which the coils are sometimes bound up to be placed in transformer as one coil.

Exciting Current.—The Exciting Current, being also called by various other names, such as leakage current, open circuit current, and magnetizing current, is a very important factor.

In order that a transformer may be ready to do its work it is always connected to the line. This means that the primary coil is always magnetizing the core, if no current is drawn from the secondary.

This steady flow of current to excite the primary is the price we have to pay for having the transformer continually ready for service.

A transformer should therefore never be left on a line unless it is needed.

Efficiency of Transformers.—The losses in transformers are less than any other piece of electrical machinery or apparatus; 98 per cent of the intake being delivered in the larger sizes as used in railroad sub-stations or power houses, when fully loaded. Unfortunately they lose about the same amount of power at all loads.

A. 100 K. W. transformer loses 2 K. W. at full load, its efficiency is then 98÷100=0.98. At half load it loses 2 K. W., but is only carrying 50 K. W., so (its losses are

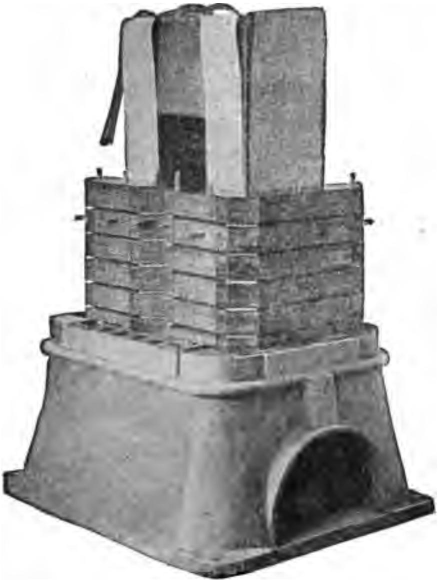


FIG. 588

INTERIOR CONSTRUCTION OF AN AIR BLAST TRANSFORMER

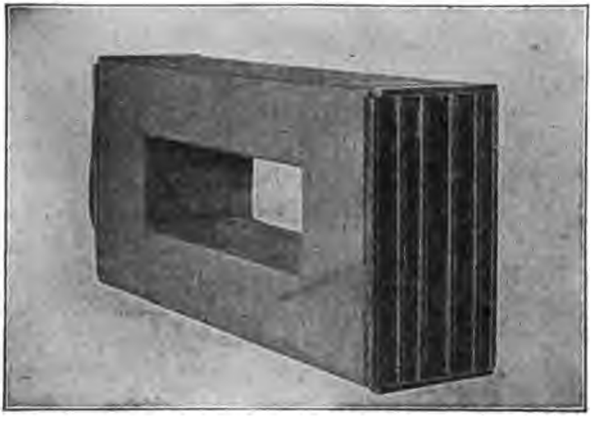


FIG. 589

SET OF COILS MADE UP READY TO BE PLACED IN TRANSFORMER now equivalent to 4 K. W. on a 100 K. W.) its efficiency is 48÷50=0.96.

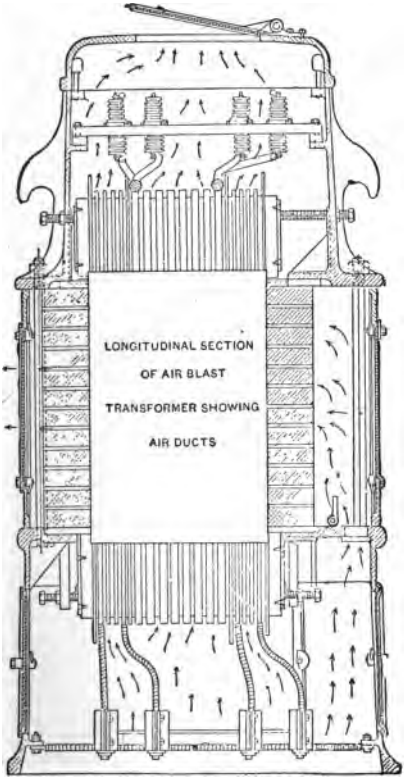


Fig. 590
AIR BLAST TRANSFORMER

At quarter load it takes in 25 K. W., loses 2 K. W., so its efficiency is 23÷25=0.92.

By clever designing transformers are built to be most efficient at three-quarters load. They are a little less efficient at half, and full loads, and still less at quarter load, and quarter overload, but never fall below 95 per cent.

Cooling Transformers.—Small transformers hung up on poles are cooled by surface radiation only.

Medium sized ones are filled with oil. This conducts the heat to the iron case, and also acts as an insulator.

The oil will also flow in and fill a break in the cloth, or mica after a puncture.

Air blast avoids the danger of oil in case of fire or flame due to short circuits. They are cheap as a transformer may be much more heavily loaded when cooled by the air blast, and the blower only consumes 1-10 of 1 per cent of the full load output of transformer.

Fig. 590 shows the interior construction of an air blast transformer and Fig. 591 shows how they are installed.

Water cooled. These are the smallest and cheapest transformers to build, but not so cheap to run as is the air blast.

The cases are filled with oil which absorbs heat from coils. Pipes are run through the oil, in which cold water is circulated.

In a water power plant where the head of water would render pumps unnecessary the water cooled type would certainly be the best.

Auto-Transformers.—These are only applicable to certain cases.

The idea is shown in Fig. 592. The same coil of wire A to B is used as primary and secondary, the whole being the primary, and portions as C to D, D to E, or C to E being used as secondary.

They are only used where the primary voltage is fairly low and the secondary voltage is not less than one-fifth of the primary voltage.

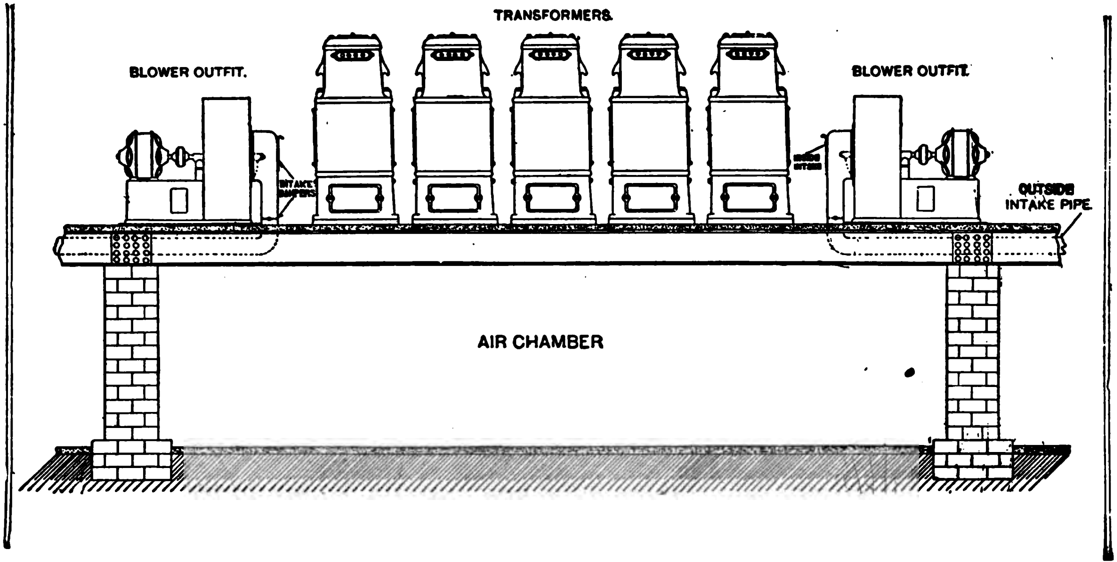


FIG. 591
INSTALLATION OF AIR BLAST TRANSFORMERS

They are used instead of resistances to start A. C. motors.

Allis-Chalmers Power Transformers.—Transformers for use on power transmission lines are made by Allis-Chalmers Company in three different types, depending on the method used for cooling. These types are as follows: oil-filled self-cooled (O. F. S. C.); oil-filled water-cooled (O. F. W. C.) and air-blast. In the first the heat is carried off by radiation, and conduction from the case; in the second by the circulation of water through coiled pipes immersed in the oil; and in the third by currents of air forced through the transformer. Oil-insulated transformers are used in the great majority of cases, and the question as to whether they shall be self-cooled or water-cooled is determined largely by the size of the units, and the available supply of cooling water.

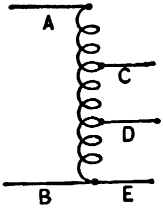


FIG. 592

DIAGRAM OF AUTO-TRANSFORMER OR COMPENSATOR

Self-cooled transformers are built in sizes up to 250 K. V. A. (kilovolt-amperes). Above this size the external surface of the case is not sufficient for the effective radiation of the heat unless the case is made abnormally large. Fig. 593 shows a standard transformer of this type.

Water-cooled transformers, Fig. 594, are made in sizes from 100 K. V. A. up. Water is circulated through a coil of seamless copper tubing immersed in the oil in the upper part of the tank, and the heat is effectively carried off. Wherever water is available and not expensive this method is preferable to air cooling, even for comparatively small transformers, as it permits operation at lower temperatures, and allows more margin for overloads.

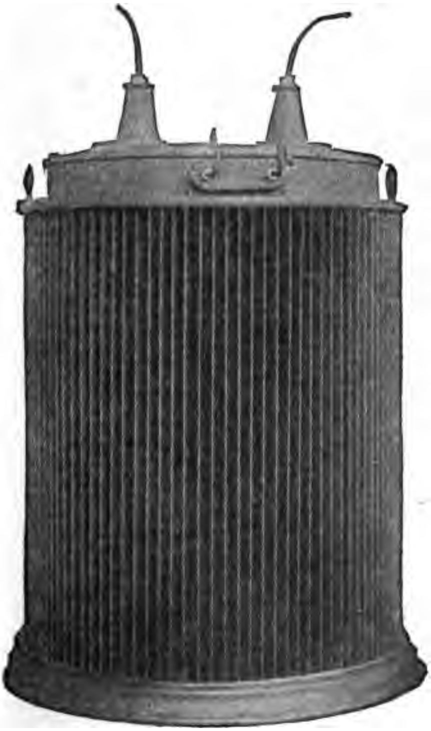


FIG. 593

ALLIS-CHALMERS OIL-FILLED SELF-COOLED TRANSFORMER, 60 CYCLE, 170 K. W., 20,000 TO 2,300 VOLTS

Air-blast transformers are made in sizes from 75 K. V. A. up. Cooling is effected by placing the transformer over

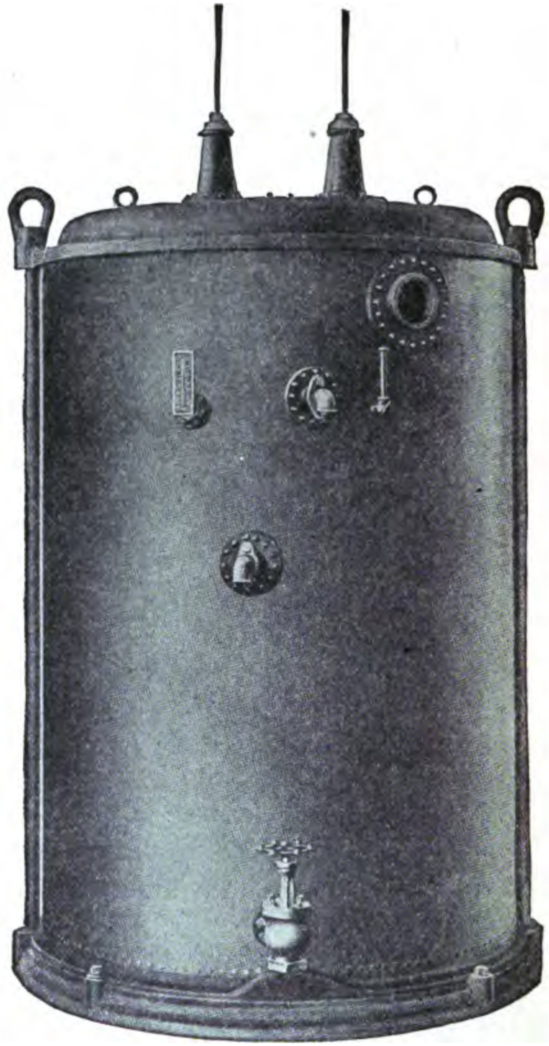


Fig. 594

ALLIS-CHALMERS OIL-FILLED WATER-COOLED TRANSFORMER, 25 CYCLE, 500 K. W., 20,000 TO 375 VOLTS an air chamber in which a pressure of air is maintained by motor driven fans; currents of air passing up around the transformer carry off the heat. In this type oil cannot be used for insulating purposes, and 25,000 volts is the highest pressure for which it is advisable to build them.

Much has been written about the relative fire risks of air-blast and oil-filled transformers, but this is a matter that depends as much on surrounding conditions, and the location of the transformers as upon the construction. The air-blast transformer contains a small quantity of inflammable matter as compared with the oil-filled transformer, but this material is much more easily ignited. A breakdown in an air-blast transformer is usually followed by an electric arc that sets fire to the insulating materials, and the flame soon spreads under the action of the forced circulation of air. Although the fire is of comparatively short duration, it is quite capable of ignitng the building unless everything near the transformers is of fire-proof construction.

The chance of an oil-filled transformer catching fire on account of any short circuit in the windings is extremely small, because oil will burn only in the presence of oxygen, and, since the transformer is completely submerged in oil, no air can get at it. Moreover, the oil used in transformers is not easily ignited; it will not burn in open air unless its temperature is first raised to about 400° F. In fact, the chief danger of fire is not that the oil may be ignited by any defect or arc within the transformer, but that a fire in the building in which the transformers are installed may so heat the oil as to cause it to take fire.

General construction.—The general construction of the coils and core is much the same in all three types, regardless of the method of cooling. All transformer coils are

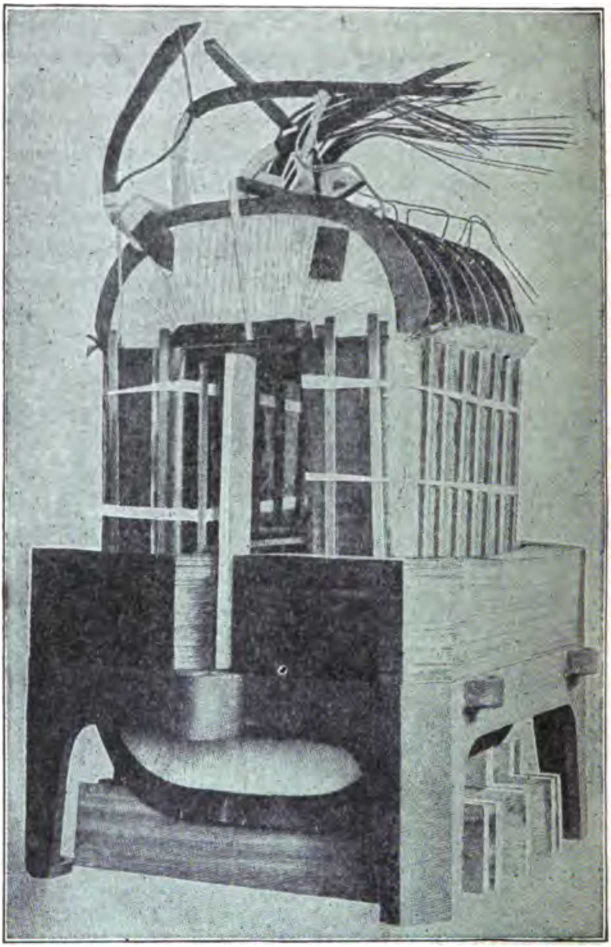


FIG. 595
PARTLY ASSEMBLED 25 CYCLE, 500 K. W., 20,000 TO 375 VOLT TRANSFORMER

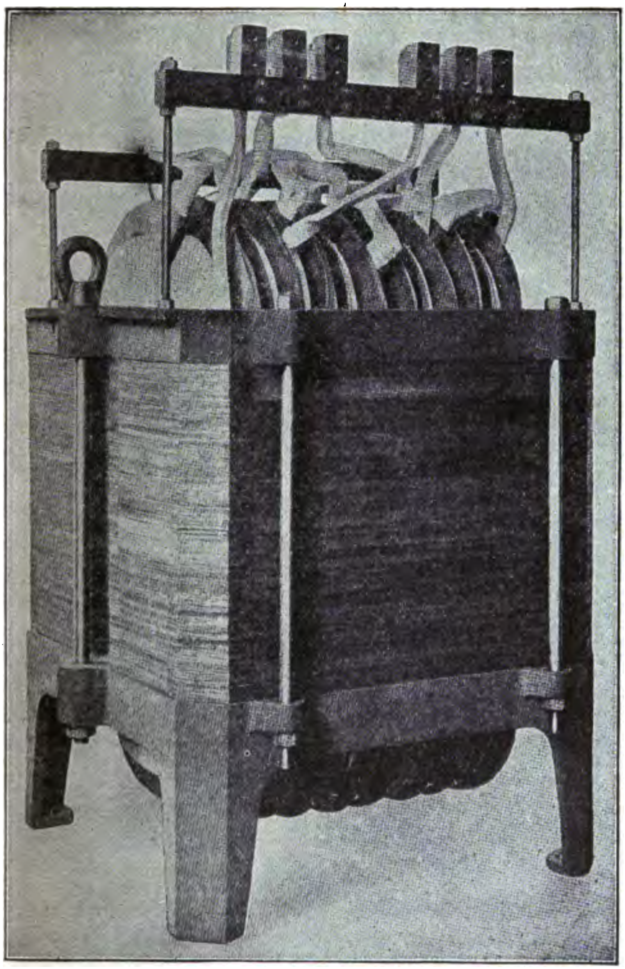
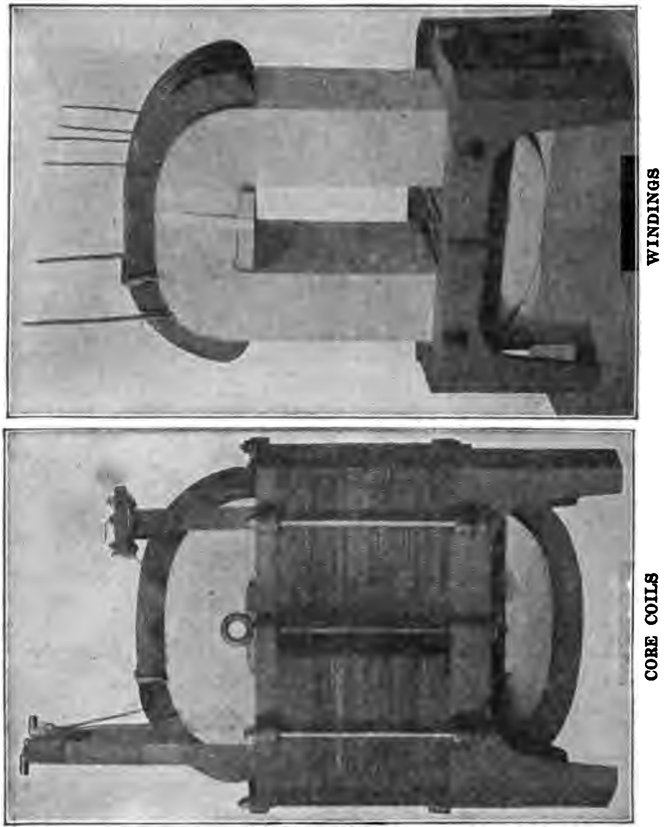


FIG. 596

CORE AND COILS, 500 K. W., 20,000 TO 375 VOLT TRANSFORMERS wound with double cotton covered strip copper, one turn per layer, with fullerboard insulation, in addition to the cotton covering, between turns. Exceptions to this construction are made only when the size of the conductor is such as to render the use of copper strip impracticable, and in such cases the coils are wound with round, double-cotton


WINDINGS

CORE COILS

Fig. 597

covered wire with few turns per layer, so that the voltage between the layers is kept within safe limits. The core is built up of steel sheets 0.0014 inch thick. In the larger sizes, space blocks are placed every few inches in the core, thus providing ducts through which oil can circulate and carry off the heat. Also, in assembling the coils, spaces are formed between the coil sections, and between the coils and core, so that all parts are in contact with a free circulation of oil. Fig. 595 shows a core partly built up and Fig. 596 core and coils completely assembled. Fig. 597 shows the windings and core for a transformer of smaller output.

ROTARY CONVERTERS.

Perhaps one of the greatest objections to the use of direct current is the inability to change its voltage without the use of moving machinery.

There is but one way to transform direct current and that is by a motor and generator.

This motor-generator set usually consists of a direct current motor driven by current at the pressure of the incoming line. This motor drives a direct current generator which furnishes current at the desired pressure.

By altering the strength of the field of the generator we regulate the outgoing pressure to suit the requirements.

The motor and generator are built on the same shaft, and set on a long cast iron base, making them mechanically one machine.

When the incoming and outgoing voltages can have the same ratio to each other always, a cheaper form of machine can be used called a Dynamotor.

This is a direct current motor running on the incoming voltages. On the same armature core is a separate winding connected to its own commutator at the other end of armature. The one set of field magnets serves for the motor winding and the generator or dynamo winding.

The Rotary Converter.—Combines in a single machine the functions of the two machines just described. In one sense it may be regarded as an alternating-current synchronous motor driving a direct-current generator, or if the machine be inverted, it may be considered a direct-current motor, driving an alternating-current generator.

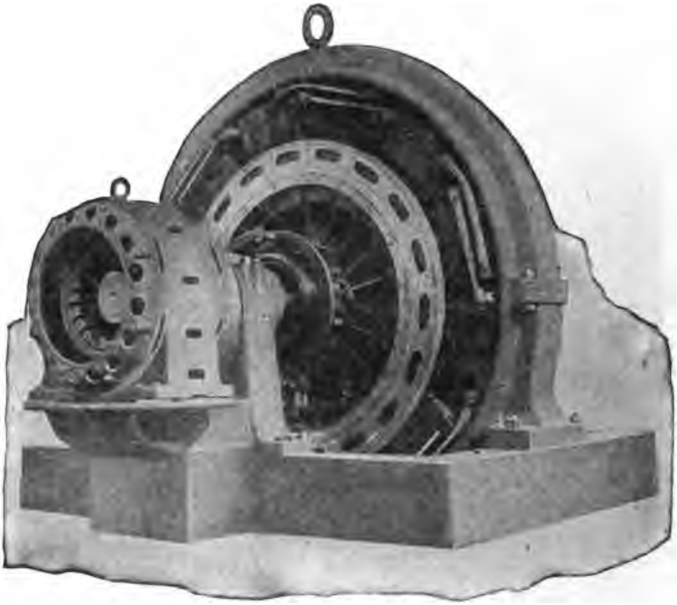


FIG. 598
WESTINGHOUSE 1,500 K. W. ROTARY CONVERTER

As direct current cannot readily be generated at, or transformed to a high voltage, which economical distribution dictates, alternating current is almost invariably used for all except very small electrical power transmissions. Wherever direct current is used, as in direct current railway lines, the alternating current must be transformed into direct current. While, of course, this can be accomplished by means of a motor-generator set, consisting of an alternating current motor connected to a direct current generator, the higher efficiency and lower cost of the rotary converter accounts for the almost universal practice of using it in preference to the motor-generator on low frequencies.

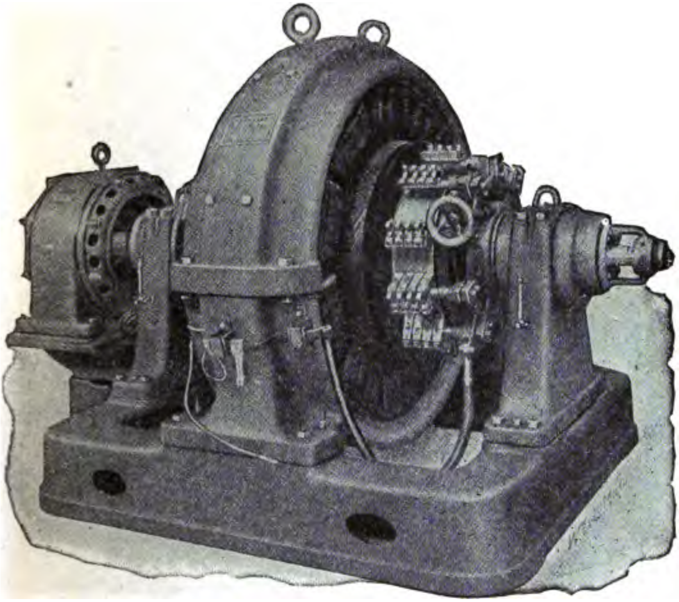


FIG. 599

WESTINGHOUSE 300 K. W. ROTARY CONVERTER, 600 D. C. VOLTS, 500 D. C. AMPERES, THREE-PHASE, 60 CYCLES

Rotary converters have many of the features which distinguish the most modern direct-current machines; the only material difference being the addition of collector rings connected to certain points of the armature winding. The number of such connections depends upon the number of poles and phases.

The machine is built for single-phase, two-phase, three-phase or six-phase circuits, although single-phase and six-phase converters are seldom desired. A two phase converter is provided with four collecting rings, and a three-phase converter is provided wth three collecting rings. As it is usually found expedient to transmit the alternating current at high pressure, transformers must be employed for lowering the potential to secure the proper direct voltage. Where the converter is operated from direct, to alternating current, transformers are usually employed to raise the voltage for transmission.

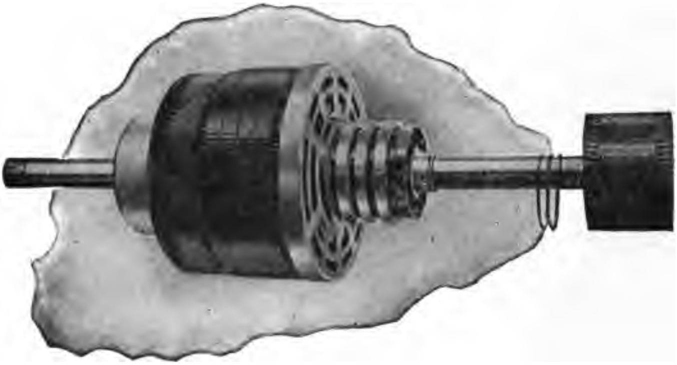


FIG. 600

WESTINGHOUSE ROTARY CONVERTER ARMATURE FROM THE COLLECTOR SIDE, 300 K. W., 550 VOLTS, THREE-PHASE

A rotary converter may be separately excited, but it is usually shunt wound, or compound wound, depending upon the nature of the service. When the load is variable, as in railway service, the machine is compound wound, which tends to maintain the direct current voltage constant, by compensating for the drop in the supply circuit as the load comes on. The ratio between the alternating and direct current voltages of a rotary converter depends upon the number of phases, upon the wave form of its alternating current, upon the lead given to the direct current brushes, and to a slight extent upon the field excitation. In any given converter, therefore, the direct current voltage depends practically upon the voltage of the alternating current applied. To a smaller extent it depends upon the armature drop, which diminishes the voltage ratio in slight proportion with the load when running A. C. to D. C. and increases the ratio when running D. C. to A. C. This will be easily seen by referring to a saturation curve.

With a sine wave the ratios of conversion are approximately as follows:

Single Phase,	Two Phase,	Three Phase,	Six Phase,
.71	.71	.61	.71 or .61

Thus if the D. C. voltage be 550 volts, the A. C., if two-phase, will be .71×550=390 volts, and if three-phase, it will be .61×550=335 volts. The ratio of conversion in the six-phase is .71 with the star connection, or .61 with the double delta connection.

The variations from these figures with wave forms in commercial use are taken into account in the ratios of the transformers used in connection with the rotary converters.

The rotary converter built by the Westinghouse Company presents in its frame the same mechanical features as are found in its well-known line of direct current machines. The machine is of the multipolar type, havng laminated steel poles, cast, or bolted to its iron yoke, and carrying easily removable field coils. If the windings are compound, the series, and shunt coils are insulated separately. The armature is of the slotted drum type, with either a two circuit, or multiple type of winding. The number of poles in a rotary converter is dependent upon the speed of the armature and the frequency, as is the case with all alternating current machinery.

This feature accounts for the difficulty in designing rotary converters for high frequencies, as the maximum armature speed is limited by the maximum safe speed of the periphery of armature and commutator. With a given speed, however, the number of poles is proportional to the frequency, and with a given maximum speed of armature and commutator periphery, the distance between adjacent poles, and therefore adjacent brush holders, is inversely proportional to the frequency. With high voltage 60-cycle converters, these facts necessitate high commutator speeds, short distances between poles, and between brush holders,

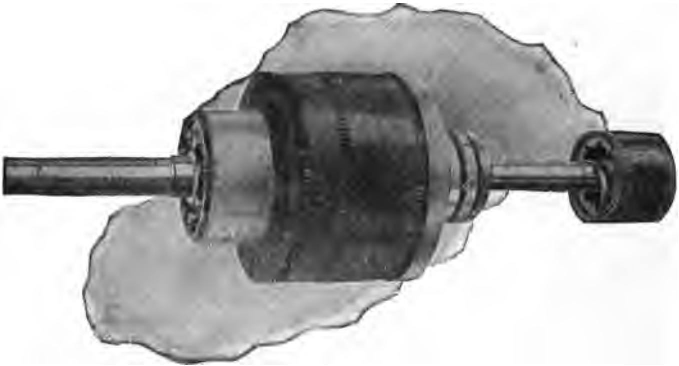


FIG. 601

WESTINGHOUSE COMPLETE ROTARY CONVERTER ARMATURE FROM THE COMMUTATOR SIDE, 300 K. W., 550 VOLTS, THREE-PHASE narrow commutator segments, and a high voltage between adjacent segments; resulting in a tendency to flashing over between brushes at sudden overload.

This should always be borne in mind when choosing the frequency of a system on which rotary converters are to be used, and it applies particularly to 500 and 600 volt railway rotary converters, which are required to withstand much more severe service than is ever experienced on lighting systems.

In the erection of a rotary converter the following considerations should, as far as possible, be observed:

First. It should not be located in a position where it would be exposed to moisture, as drippings from pipes, or escaping steam.

Second. It should not be exposed to dirt or dust, especially from coal.

Third. It should be located in as cool and well ventilated a place as possible. The temperature of the machine depends upon the temperature of the air surrounding it.

Fourth. It should be so located as to allow easy access to the alternating current brushes, and also to the commutator. These are the parts requiring special attention. Rotary converters should be set on substantial foundations in order to prevent vibration when running.

The following list of instructions refer more particularly to Westinghouse machines, but much of it will apply to others.

Insulation of Frame.—Whether the frame should be insulated from the ground is a matter to be determined by the engineer in charge of the plant, but rotary converters are usually not insulated. However, the following remarks which apply to alternating practice, may not be amiss: Generally speaking, the strain on the insulation of the windings will be decreased, and the danger to the attendant increased by insulating the frame. When, however, it is considered advisable to insulate the frame, the foundation should be capped with a strong wooden frame bolted down. The bolts which hold this frame to the masonry should not come in contact with those which hold the machine to the frame, nor should any metal, or electrical conductor unite the two sets of bolts.

The wooden insulating frame under the machine may also be covered with some insulating waterproof paint or compound.

Erection of Machine.—When placing the parts of a machine in position the following points should be observed:

(1) Set the lower half of the field in position and place the armature in its bearings, having first carefully examined the bearings and oil wells to be sure that they are clean and free from dirt. Be sure that the oil rings are in place and in good running order.

(2) Clean the contact surfaces of both halves of the field and file off the burs, if any exist, to secure perfect magnetic joints at the division of the yoke.

(3) Set the upper half of the field in position and secure it to the lower half by means of the field bolts and feather keys.

(4) Note that the machine is to be perfectly level along the axis of the shaft, except that when an oscillator is attached the machine is placed slightly out of level, as will be pointed out later.

Armature.—Never try to support any of the weight of an armature by the commutator or collector rings. Do not allow these parts to rest on any blocking, and do not pass a rope around them for the purpose of lifting. When handling the armature always support it with a rope slung about the shaft, and be careful not to mar or scratch the shaft, as any roughness would cause it to cut the bearings and so produce heating when the machine is running.

In putting the armature in the field be careful not to scratch the bearings, nor to bend the oil rings.

Coils. Assembly or field coils.—The field coils of the larger machines are shipped separately. The coils are held on the poles by the dampers, which should be bolted to the pole pieces. The coils on each of the separate halves of the field should be properly connected before the machine is set up.

Each pole piece has a number stamped with steel stencil and also painted in red, and a red line is drawn parallel and near to one edge of the pole. This line and number correspond to similar marks inside the coil. In erecting, place the coils on the poles so that the marks coincide.

If a rotary converter has been exposed to dampness it may be dried out by employing one of the following methods:

(1) Short-circuit the field and apply to the collecting rings about 10 per cent of normal alternating current voltage, which may usually be obtained from the lowering transformers. During this application the D. C. brushes must be raised and the rotary must be at a standstill. The standard Westinghouse transformers are usually provided with taps, between which a low voltage may be obtained.

(2) Run the rotary converter, driving it by a suitable motor, and short-circuit the armature on the direct current side with very weak field excitation. If shunt wound, separate excitation at very low voltage must be used. If the converter be compound wound, the armature may be short-circuited through the series field coils. As rotary converters are usually very sensitive as series machines this

method should be undertaken only by those who are thoroughly experienced, as there is danger of excessive current.

(3) Dry the field coils from a source of separate excitation, with about two-thirds of the normal D. C. voltage. This will also dry the armature somewhat. While drying out, the temperature of the accessible parts should be watched closely, and not be allowed to exceed 75° C.

In drying out with current there is always danger of overheating the windings, as the inner parts may get injurously hot because they cannot quickly dissipate the heat generated in them. Coils containing moisture are more easily injured by overheating than those which are already dry. Several hours, or even days, may be required for thoroughly drying out.

Repairs to Armatures.—The instructions pertaining to armature troubles, and repairs to commutators and other parts of electric generators, will also apply in the case of rotary converters.

Bucking.—Bucking is the expressive name given to the action of the rotary converter when arcing occurs between two adjacent brush holder arms, thereby short-circuiting the machine. Bucking is, in general, due to abnormally high voltage, or a path of low resistance over the commutator surface, or to abnormal commutation conditions. The poorer the commutation, the more liable will the machine be to buck whenever these abnormal operating conditions occur. Some of the particular causes for bucking are the following:

a) Rough or dirty commutator. A drop of water falling on the commutator has been known to cause the machine to buck.

(b) Excessive voltage due to increase in A. C. voltage.

(c) Excessive voltage due to static disturbances from lightning arrester short-circuits.

(d) Excessive voltage due to static discharge from or through lowering transformers. When bucking is due to this cause, it will usually occur when switching is done in the high tension circuits.

(e) Bucking may be caused by fluctuations in the voltage, due to the removal of a short-circuit.

In multiple wound rotary converters, balancing rings or cross-connections are employed as in direct current generators. These rings connect together points of equal potential around the commutator.

By this means the same field strength is obtained under each pole.

Oscillators.—The armature of a rotary converter revolving with its horizontal shaft will take up normally a fixed position relative to its bearings, and the frame of the machine, and revolve without any tendency to move or oscillate in the direction of its length. This is detrimental to its best operation as the brushes are liable to wear grooves in the commutator, and collector. It therefore becomes necessary to provide a means of producing a periodic movement of the armature in the direction of its length, and this function is performed by the oscillator.

There are two classes of oscillators, viz.: mechanical and magnetic. The mechanical oscillator employed by the Westinghouse Co. is described as follows:

This device is self-contained and is carried over one end of the shaft. The operating part consists of a steel plate grooved by a circular ball race in which travels a hardened steel ball. The steel plate is not quite parallel to the face of the end of the shaft. The normal position of the ball is at the lowest point of the circular race. The steel plate is backed by a spring.

The machine is leveled so that the armature is slightly inclined toward the oscillator. The steel plate is then adjusted so that when the ball is at its bottom position it just comes in contact with the shaft end. As the armature revolves the ball is carried up the race, and owing to the inclination of this race, compresses the spring. The reaction of the spring drives the shaft away. Thus the armature receives an impulse, which moves it toward the other limit of its travel, and it continues to move until the opposing forces bring it to rest and start it back to its normal position, where it again comes in contact with the ball, and the operation begins over again. Fig. 602 shows a diagrammatic view of the Westinghouse magnetic oscillator, of which

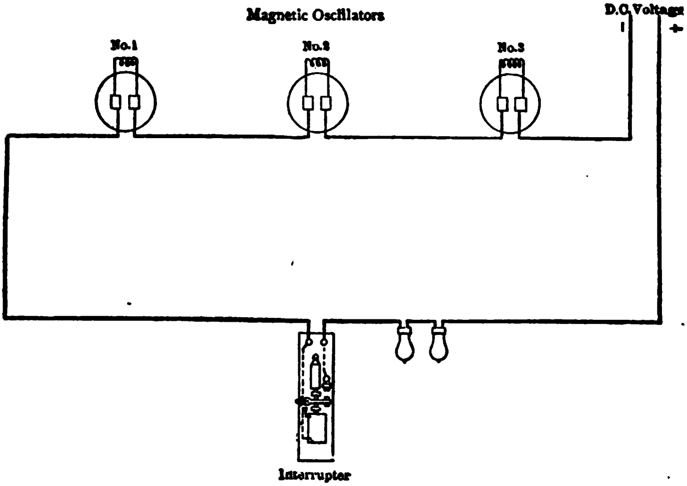


FIG. 602

DIAGRAM OF CONNECTIONS FOR MAGNETIC OSCILLATOR the following is a description. A magnet is mounted upon one of the bearing housings of the rotary converter in such a manner as to attract the end of the shaft. When the circuit is closed the magnet draws the shaft toward it and when the circuit opens, the armature tends to resume its normal position which is determined by the leveling of the converter. The magnet has in series with it a make and break device called an interrupter which is controlled by a dash-pot to secure the proper frequency of action.

As the dash-pot offers an adjustable resistance, the frequency of the impulses is adjustible. When there are a number of rotary converters in the same sub-station, the magnetic oscillators are connected in series, and controlled by a single interrupter.

Under certain conditions the commutator, and collector surfaces of machines provided with oscillators may be worn in irregular wavy grooves.

When this occurs it will then be necessary to turn down the commutator and collector.

QUESTIONS AND ANSWERS.

891. What is the function of a transformer?

Ans. To transform the current from a higher, to a lower voltage, or vice-versa.

892. What principles govern the action of a transformer?

Ans. The principles of electro-magnetic induction.

893. What is a step up transformer?

Ans. A transformer that raises the voltage.

894. What is a step down transformer?

Ans. One that lowers the voltage.

895. How are transformers cooled?

Ans. Small sizes by surface radiation. Larger sizes by oil; also by air blast. Some of the smaller sizes are cooled by water circulating through surrounding coils.

896. How is direct current transformed from one voltage to another?

Ans. By means of a machine called a motor-generator.

897. Describe in brief a motor-generator.

Ans. It consists usually of a D. C. motor driven by current at the voltage of the incoming line. This motor in turn drives a D. C. generator that furnishes current at the desired voltage.

898. How is the outgoing voltage regulated?

Ans. By altering the field strength of the generator.

899. In case the incoming and outgoing current can bear the same ratio to each other constantly, what kind of an apparatus is used?

Ans. A machine called a dynamotor.

900. Describe the operation of a dynamotor.

Ans. It is a D. C. motor running on the incoming voltages. On the same armature core is a separate winding connected to its own commutator at the other end of the armature. One set of field magnets serves for the motor winding and the generator or dynamo winding.

901. Describe in general terms a rotary converter.

Ans. It combines in a single machine the functions of a motor-generator, and a dynamotor.

902. Why are rotary converters and transformers necessary?

Ans. Because it is more economical to transmit alternating current at high voltages and transform, or convert it to the lower voltage at which it is used.

903. Give another reason for using rotary converters.

Ans. For the purpose of transforming alternating current into direct current when direct current is used.

904. What is the chief point of difference between a rotary converter and a direct current generator?

Ans. The rotary has collector rings connected to certain points of the armature winding.

905. What governs the number of such connections?

Ans. The number of poles and phases.

906. Describe the different types of rotaries.

Ans. They are built for single-phase, two-phase, three-phase or six-phase.

907. How many collecting rings has a two-phase converter?

Ans. Four collecting rings.

908. How many collecting rings has a three-phase converter?

Ans. Three collecting rings.

909. When alternating current is transmitted at high pressure, what means are employed for lowering the potential?

Ans. Transformers.

910. When the incoming current is direct and the outgoing current alternating, how is the voltage raised?

Ans. By step up transformers.

911. Describe the winding of a rotary converter.

Ans. It is usually shunt wound, or compound wound, although sometimes separately excited.

912. How are rotaries in railway service usually wound?

Ans. Compound, owing to variations in the load.

913. What advantage is gained by this method of winding?

Ans. It tends to maintain the D. C. voltage constant.

914. Upon what does the ratio between the A. C. and D. C. voltages of a rotary depend?

Ans. Upon the number of phases, the lead given the D. C. brushes, the wave form of its alternating current, and upon the field excitation.

915. Does the armature drop affect this ratio to any extent?

Ans. It does by decreasing it slightly when running A. C. to D. C. and increasing it when running D. C. to A. C.

916. What are the ratios of conversion approximately?

Ans.

Single-phase	.71
Two-phase	.71
Three-phase	.61
Six-phase	.71 or .61

917. Give an example illustrating above.

Ans. If D. C. voltage is 550 volts, the A. C., if two-phase will be 500×.71=390 volts, or if three-phase it will be 550×.61=335 volts.

918. What precautions should be observed in the erection of a rotary converter?

Ans. First—It should be protected from moisture. Second—It should be protected from dust or dirt. Third—It should be in a well ventilated room and kept as cool as possible.

919. Should the frame of the machine be insulated?

Ans. Generally speaking the strain on the winding insulation will be decreased, and danger to attendant increased by insulating the frame.

920. If a rotary has been exposed to dampness how may it be dried out?

Ans. By running it with about 10 per cent of the normal A. C. voltage, while at same time observing certain precautions noted in the text of this book under head of rotary converters.

921. What method should be pursued in caring for the commutator?

Ans. Wipe it off with a piece of canvas—never use waste. Lubricate it with a very small quantity of vaseline, or oil applied with a piece of cloth. See that none of the segments is at all loose.

If it gets out of true turn it down.

922. If a commutator gets hot while carrying only a normal load what should be done?

Ans. Heating under such conditions is an indication that the commutator is worn out, and should be replaced by a new one.

923. Give some of the causes of sparking at the brushes.

Ans. Brushes may not have proper lead.
Brushes may not fit commutator.
Brushes may be burned on end.
Commutator surface may be rough.

924. What is meant by a rotary bucking?

Ans. When arcing occurs between two adjacent brush holder arms, thus short circuiting the machine.

925. Name a few of the principal causes of bucking.

Ans. Rough or dirty commutator.
Excessive voltage.
Fluctuations in the voltage.

926. What is an oscillator, and what is its function?

Ans. An oscillator is a device operated either magnetically, or by mechanical means, and its function is to produce a slight, periodic movement of the armature shaft endwise.

927. Why is this endwise movement of the shaft necessary?

Ans. In order to prevent the wearing of grooves in the commutator.

928. What is meant by the hunting of a rotary converter?

Ans. It is a slight change of the speed of the armature.

929. What is the cause of hunting?

Ans. Irregularities in the speed of the generator delivering current to the rotary, thus causing a slight difference in the relative positions of the armature of the two machines, resulting in a change in the phase positions of the generator E. M. F. and the counter E. M. F. of the converter.

930. What are the usual methods of starting rotary converters?

Ans. First—By a separate A. C. starting motor.

Second—By applying direct current to the commutator. This starts the converter as a shunt motor.

Third—By applying alternating current directly to the collector rings. This starts the converter as an induction motor.

931. What is meant by synchronizing a rotary converter?

Ans. Bringing it to the same frequency, the same phase, and the same voltage as the generator from which it is receiving current.

932. What method is employed to determine when the machines are in synchronism?

Ans. There are several methods, the most common one being by means of incandescent lamps connected in series with the two machines.

933. What is a synchroscope?

Ans. It is an instrument for determining when electrical machines are in synchronism.

934. What is an automatic synchronizer?

Ans. It is a device that will automatically synchronize two electrical machines; also connect a synchronized machine with the main by means of an electrically operated switch.

935. Name two important points to be looked after before starting a rotary converter.

Ans. First—See that both the A. C. and D. C. brushes are properly adjusted and that every thing is clear about the converter. Second—See that the switches on board are open on both the A. C. and D. C. sides, and that the resistance of the rheostat is all cut in the field circuit.

Oil Switches

As considerable space has been devoted to oil switches, the subject will be continued still further by a brief explanation of the construction and operation of this type of switches, and also of oil circuit breakers. The principle of construction is shown in Fig. 603. On the right and left hand are two metallic rods which descend through insulating blocks, and carry springs at their lower end projecting therefrom. Another metallic rod descends between these two, and carries a cross-piece at its lower end, having beveled carbon contacts C. C. facing upward. This rod moves up and down through an insulating block, and it is connected to one lead of the circuit, while both side rods are connected

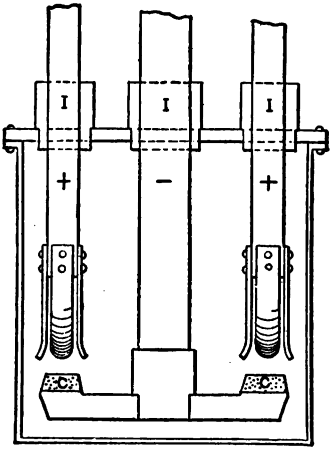


FIG. 603

to the other. When the central rod is raised the carbon blocks C. C. enter between the springs and make the contact, closing the circuit. When lowered it opens the circuit. Thus far the action of the switch is similar to the ordinary switch, but in order to prevent the formation of arcs, and to insure definite action in the opening or closing of the circuit, the lower portion of the mechanism is immersed in oil contained in a tank which is shown in section in the diagram

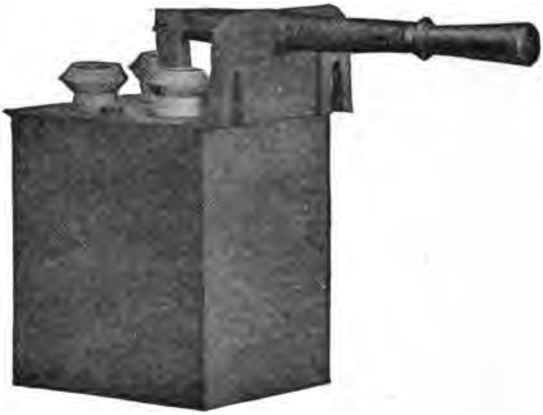


FIG. 604
TYPE I WESTINGHOUSE OIL SWITCH

Fig. 603. Oil switches are made in many different styles, but the one feature of the complete submersion of all live parts in oil, governs all. They are also as a rule held in the open position, either by gravity or by special locking mechanism consisting of a safety catch that holds the switch open until released by pressure of a button in the end of the operating handle.

The development of the oil switch, and circuit-breaker has produced what is probably the most valuable addition to high-potential line apparatus made during the last ten years. It is indeed likely that the development of high-tension transmission of power would have been very seriously hampered but for the invention of the oil switch.

This use of oil has made it possible to rupture easily and safely, circuits carrying heavy currents at high voltage and, further, to open these circuits under conditions of short circuit. The possibility of opening high-tension circuits under conditions of heavy overload has made possible the development and application of the present system of relays.

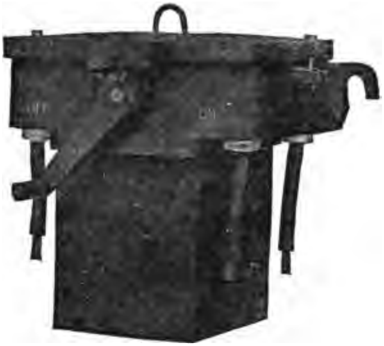


FIG. 605
TYPE D WESTINGHOUSE OIL SWITCH

By means of these relays, used in connection with oil circuit-breakers, perfect protection can be secured for the apparatus to which they are applied.

The term "switch" is given to those pieces of apparatus in which the contacts are similar to the ordinary switch, and are opened and closed by hand. Devices in which the contacts tend to separate, and are only held in a closed position by means of triggers and toggles are called "circuit-breakers."

The Westinghouse oil switches are essentially knife switches immersed in oil, the blades being connected to a common operating lever by specially treated wooden rods. The knife-blade contacts are used, as they give the most perfect contact and therefore the lowest temperature rise.

Fig. 604 shows a Westinghouse type I oil-switch for switchboard use only. Fig. 605 shows the type D Westinghouse oil-switch for outdoor service, the casing being moisture proof, and the leads brought out underneath through sealed bushings as shown. Fig. 606 shows the same switch with the oil tank removed. Fig. 607 shows the Westinghouse type B oil circuit-breaker, designed for potentials from 3,300 to 22,000 volts, and currents from 300 to 1,200 amperes. This device is a double-break, oil circuit-breaker. It may be automatic or non-automatic, and may be placed on the back of the switchboard, or arranged for distant control through rods and levers.

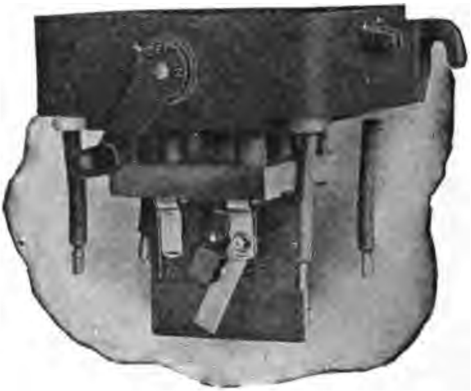


FIG. 606

Through a very simple system of levers, the operating handle is connected to a cast-iron cross bar, to which are fastened the movable contact arms. To the lower end of the wooden arm is fastened a metal yoke with a conical contact on either end. When the circuit is closed these contacts engage with two stationary contacts, forming one

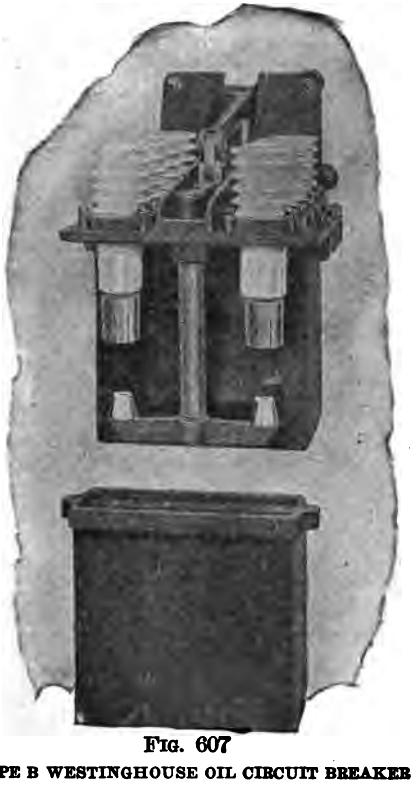


Fig. 607

TYPE B WESTINGHOUSE OIL CIRCUIT BREAKER

pole of the breaker. Each stationary contact is supported by a porcelain insulator, rigidly secured to the frame. The leads are brought to the terminals of the stationary contact within the insulator, forming an unbroken and continuous insulated conductor between the circuit-breaker, and the bus-bar or line. Each pole of the circuit-breaker has a tank in which its live metal parts are immersed in oil, each tank being entirely independent of the adjacent one.

These tanks have a lining so formed as to reduce the quantity of oil required and which serves as a barrier between the two stationary contacts, yet allowing ample space for the movement of the wooden arm and its contacts. The lining serves as an insulation, and reduces to a minimum all danger of the arc communicating through the oil. Any one of the tanks may be removed without interfering in any particular with the others. **Fig. 608** shows the type **E**

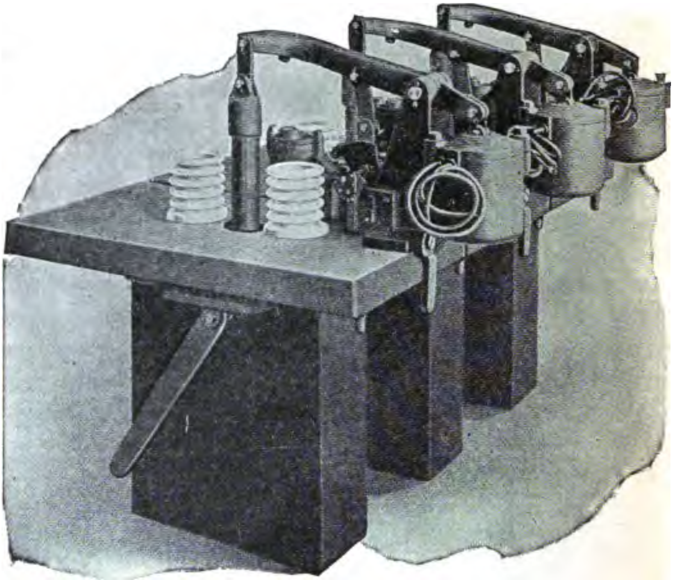


FIG. 608
TYPE E WESTINGHOUSE OIL CIRCUIT BREAKER

Westinghouse oil circuit-breaker, electrically operated. This circuit-breaker is also designed for high potentials, and heavy currents.

A simple system of toggles and levers is mounted on the top of the breaker, and a powerful electro-magnet is arranged with its movable core attached to the lever system, so that when it is drawn into the coil, the circuit-breaker will be closed. A small single-pole, double-throw switch is mounted on the breaker, and is operated by the motion of the levers in opening or closing the circuit; it controls the tell-tale indicator, and lamp which are mounted in view of the operator. These circuit-breakers are operated by 125 volts direct-current, and are calibrated for 3,000 alternations.

ELECTRO-METERS.

Galvanometers.—An electric current passing near a magnetic needle deflects the needle, and if the current is passed first over the needle and then back under it in an opposite direction, the needle will be still further deflected.

An instrument consisting of a coil of wire carrying the current to be tested, and a magnet; the two being so arranged that one can be deflected, is called a galvanometer.

There are two types, the Thompson and the D'Arsonval.

The Thompson type has the coil of wire stationary, and the light magnetic needle suspended by a silk thread. These can be made more sensitive than the other type, but are not portable, and external fields have a great influence on them, causing them to give false indications. This is prevented by thick soft iron cases, much too heavy to be carried around.

The silk suspension makes the needle sensitive to vibration.

It is a fine laboratory instrument, and with modified construction has been used in the workshop and field, but for this work the D'Arsonval is much better.

The D'Arsonval type has a very small, light coil of wire suspended by a fine bronze wire between the poles of a stationary magnet. Since the movable part is not a magnet except during the actual instant of the test, outside magnetic fields have no influence on its motion. To shield it during test, a thin soft iron or steel case is put on the instrument which does not affect its portability. These covers are usually copper, brass or nickel plated for appearance sake, but the actual material is iron for the purpose of shielding the instrument.

These D'Arsonval galvanometers are not so sensitive as the other type, which for ordinary work is a great advantage.

Both of these types have the needle swinging over a circular scale divided into degrees, or may have a small mirror attached so that the deflection may be read by the motion of a spot of light moving along a long ruler supported about a yard away from galvanometer.

As mentioned before, twice the current does not give twice the deflection, but by sending known currents through a galvanometer, and marking a scale with pen and ink we could make an ampere meter. This is called Calibration.

Ammeters and Voltmeters.—The ammeters and voltmeters of commercial work are all special adaptations of the D'Arsonval galvanometer or, for the least accurate work such as on switchboards; they are of the magnetic vane type.

The Weston instruments are D'Arsonval galvanometers.

Fig. 609 shows an instrument with the cover removed. A large permanent magnet of U shape is supported by a gun-metal casting screwed to the ends of the limbs, and

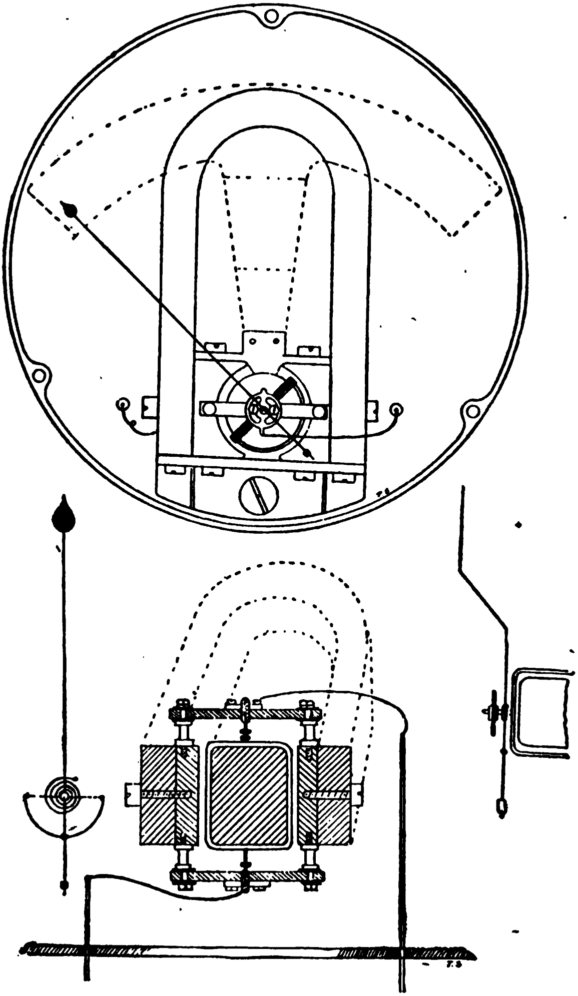


FIG. 609

INTERIOR OF WESTON INSTRUMENT

springs, the angular movement of the coil depending on the strength of the current in the coil and the strength of the field in which it is placed.

To the coil is attached a pointer of aluminum, the whole being balanced so that the instrument can be read in any position, and the pointer and scale are bent up so as to come near the front of the case.

A perspective view of the movement is shown in Fig. 611.

In this instrument the whole current does not go through the coil, but only a small fraction of it. The main part of the current crosses from one terminal to the other by a broad strip of metal under the base of the instrument, while the coil is placed as a shunt across the terminals, or as a conductor in parallel with the metal strip (Fig. 612), and consequently the ratio of the currents in the strip and in the coil will be inversely proportioned to their resistances. Now with a given strength magnetic field due to the magnet and a given elasticity of the spiral springs, it will require a certain number of ampere turns in the coil to produce the full deflection on the scale. This can be secured by adjusting the resistance of the strip connecting the terminals so that the same movement will do for any instrument. Thus, suppose the instrument were required to read to a maximum of 10 amperes, and we required 1 ampere in the coil to give the maximum deflection, then the resistance of the coil must be 9 times that of the strip, so that the current will divide at the terminals, 9/10 going through the metal strip and 1/10 through the coil. If the instrument is required to read to a maximum of 100 amperes, then the metal strip must have 99 times less resistance than the coil, and the current will then divide at the terminals, 99/100 going through the strip and 1/100 going through the coil, which will give a reading to the full range of the scale as before. By the arrangement of the pole pieces, and wrought iron cylinder the field due to the permanent magnet is practically uniform over the range of movement of the coil, and so the scale readings are the same size throughout. Should the permanent magnet vary in strength, the instrument would not read correctly, but the magnets are so treated that the falling off in strength over a number of years is inappreciable.

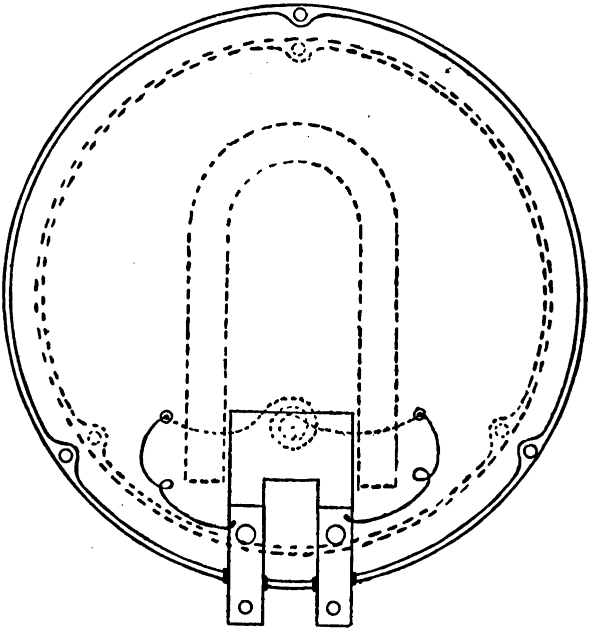


FIG. 612

MAGNET AND SHUNT OF WESTON AMMETER

The strip or shunt for portable instruments is always inside the case, while for switchboard instruments the shunt is too large (Fig. 613) and is placed separately on the back of the board. Leads are run along the board to the meter terminals which project through holes in the board from the meter which is in front.

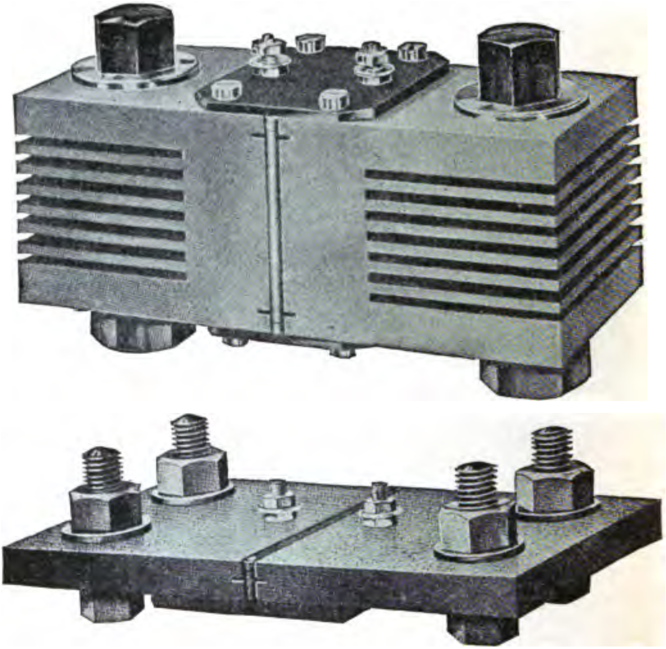


FIG. 613

EXTERNAL SHUNTS FOR AMMETERS. 1000 AND 5000 AMPERE SIZES

Such a switchboard instrument is shown in Fig. 614 and Fig. 615.

A Voltmeter is made by removing the metal strip or shunt connecting the terminals and placing a resistance coil in series with the moving coil.

As it takes 1/100 amperes to swing the pointer over full scale for every volt the instrument reads, it must have 100 ohms in the resistance coil.

A 500 volt instrument will have 500,000 ohms resistance, and hence 1/100 amperes will flow through the moving coil.

The moving coil is wound on a copper, or aluminum frame, which when it swings has current induced in it by the magnets and stops vibrating very quickly; in fact, you cannot detect any vibration. The needle seems to move to a certain spot and stop dead. This is called a "dead beat" needle.

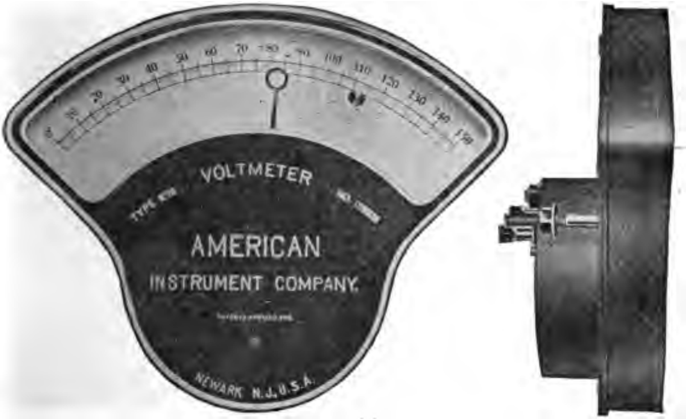


FIG. 614
SWITCH BOARD INSTRUMENT

Some instruments have electro-magnets instead of permanent magnets. The Thomson Astatic instruments are of this type. Two of these instruments are shown in Figs. 615 and 616. This latter has a scale or dial of opal glass with an electric light behnd it. This makes the instrument easily read from a distance or at night. These are called "illuminated dial instruments."

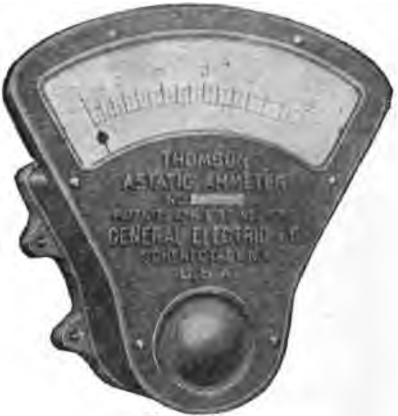


FIG. 615

SWITCH BOARD AMMETER

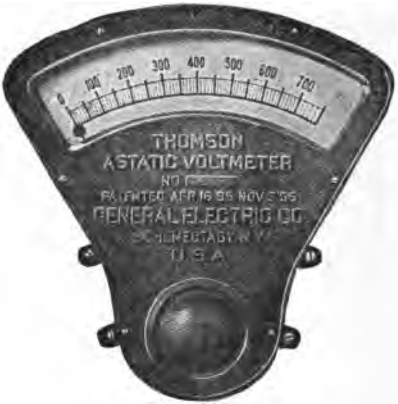


FIG. 616

ILLUMINATED DIAL INSTRUMENT

The instrument shown in Fig. 614 has an extra hand ending in a ring. This can be set at the voltage it is desired to maintain. The most hasty glance will then show whether the voltage is too high or too low.

In order to save space on switchboards some instruments are made thin and broad and are set horizontally or vertically.

Fig. 617 shows the exterior and interior of a Thomson Edgewise Ammeter.

The Thomson Inclined Coil instruments as shown in Fig. 618 are portable instruments used for alternating current only. In an emergency they can be used to measure direct current by reading, then reversing current, reading again, and averaging results.

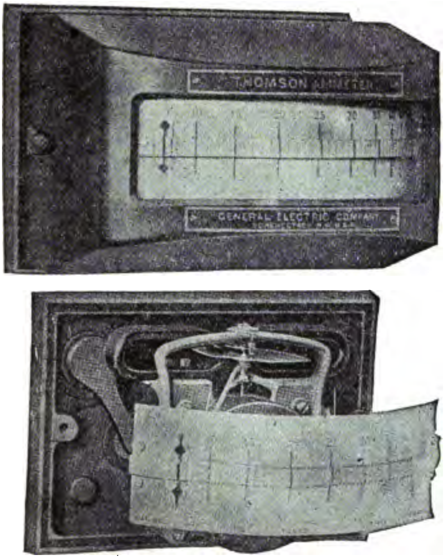


FIG. 617

THOMSON HORIZONTAL AMMETER

The action of the magnetism of the inclined coil is to twist the inclined sheet iron vane "a" around to the dotted line position.

The Weston instruments described are for direct current only. The company makes an alternating current voltmeter but no ammeter. Thomson Astatic instruments are for direct current. The Thomson Inclined Coil in portable, or edgewise switchboard form is for alternating current.

Wattmeters.—By combining two coils, one movable, the other stationary, one attached as a voltmeter with series resistance, the other attached as an ammeter, with a shunt, we get an instrument whose needle indicates power or watts. These are called indicating wattmeters.

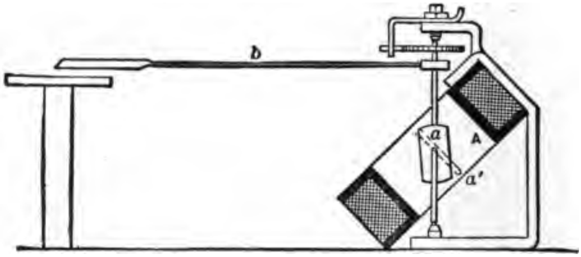


FIG. 618

THOMSON INCLINED COIL INSTRUMENT

The recording wattmeter records watt-hours. A watt-hour is one watt of power used for an hour, or any combination like one-quarter of a watt for four hours, etc.

The Thomson Recording Watt-Hour Meter is used for direct, or alternating current. It is shown with dust-proof case removed in Fig. 619. The connections made to it are shown in Fig. 620. By "lights" in the figure must be understood any load at all.

The meter consists of an electric motor whose armature A, Fig. 620, is supplied with current from the mains through a high resistance P in the back of the instrument, and a small field coil on right-hand side.

This armature is in shunt across the circuit, hence its current is proportional to the voltage.

The main current passes through the field F, hence the strength of the field is proportional to the current.

The speed of the motor is therefore proportional to both current and voltage, that is to the power, or watts.

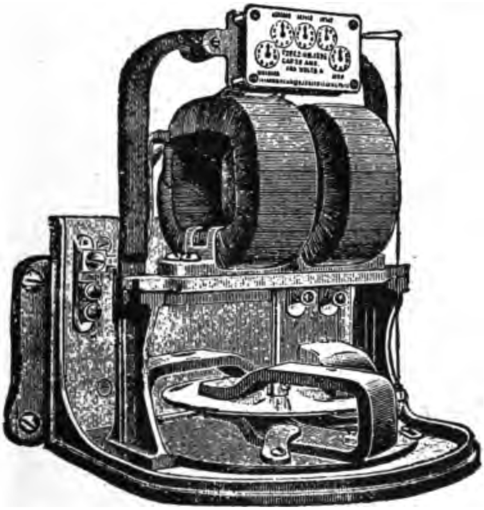


Fig. 619
THOMSON RECORDING WATT-HOUR METER

The armature shaft goes on past the commutator, to a cyclometer with dials like a gas meter. The revolutions are here recorded as watt-hours.

The auxiliary field is just strong enough to nearly overcome the friction in the bearings and cyclometer, so that the smallest current through the mains will produce rotation.

At the bottom of the armature shaft is an aluminum disc revolving between the poles of permanent magnets.

This device prevents the meter from running at too great a speed and gives an adjustment for accuracy.

The further out the magnets are swung the faster is the motion of the metal passing between their poles, and the greater a retarding effect they produce.

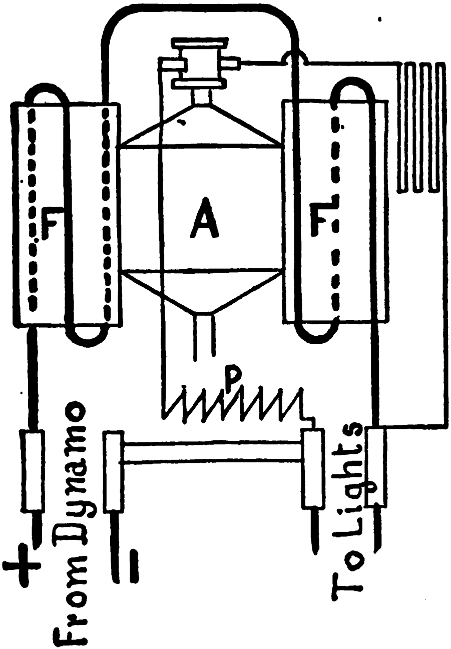


FIG. 620

DIAGRAM OF CONNECTIONS. THOMSON RECORDING WATT-HOUR METER

A meter running too slow from age, or dirty bearings could be brought up to proper speed by swinging the magnets in a little.

For heavy currents the appearance of the meter is quite different, as is shown in Fig. 621. The retarding device is enclosed in a case, and the whole instrument is enclosed in a dust-proof glass case.

Switchboard Maintenance.—The increasing relative cost of switchboard apparatus in power plants justifies more thorough inspection on the part of attendants than at present obtains in many installations. There is a feeling in some quarters that if a switchboard is blown out every day with compressed air, and the instruments wiped with a dust cloth, nothing further in the way of inspection need be done until something goes wrong.

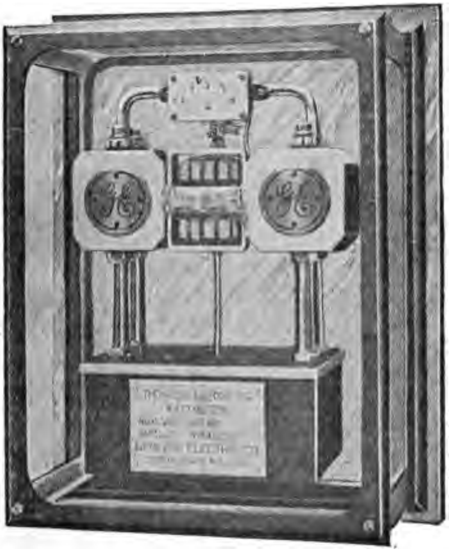


FIG. 621

LARGE CAPACITY THOMSON RECORDING WATT-HOUR METER

There are more moving parts on a modern switchboard than one would at first suppose, and a certain amount of attention is an essential of continuous reliable service. In addition to the indicating and recording instruments there are time limit relays, circuit-breaker controls, oil switch mechanisms and other contacts to look after, while the possibility of overheated parts of switches and coils is always present. Oil switches in operation should be inspected for overheating at least three times a day during the heaviest part of the load, and the binding posts of potential transformers, regulators and instruments should be looked after every two or three weeks with an eye to their becoming loose.

The oil tanks on oil switches ought to be dropped certainly once in three months, and the contacts carefully examined to locate any broken or bent springs, burned contacts or loose connections. When these contacts are cleaned with a file or in any way where there is a chance of personal connection with the wiring system, the utmost care is essential that current should be cut off, and high-potential contacts avoided. Knife switches for simple disconnecting work are worth many times their cost.

The solenoid equipment of time-limit relays are often neglected for long periods. The adjustment of these devices should be tested every two or three months and the contacts cleaned with the finest sandpaper or emery cloth. There is a tendency sometimes to forget that these relays are delicate apparatus. The adjustment of spring tension to hold contact pieces in place and the varnishing of solenoid plungers need to be carefully done. No little trouble can arise by careless varnishing of plungers so that they stick in one position and do not respond to the load variations above normal. Another point likely to be neglected is the care of the leather diaphragm on the relay bellows. This should be dressed with neatsfoot oil every two or three months to prevent it from becoming stiff and hard. Lightning arresters should always be examined and placed in condition after a storm; rheostat contact points, fixed and movable, carbon brakes and copper feeder and switch jaws all need regular inspection just as much as commutators, brushes and bearings.

LIGHTNING ARRESTERS.

Ordinarily a lightning discharge, which is an equalization of potential between the earth, and either clouds or saturated atmosphere above the earth, will take place through the path of least resistance, but, as pointed out by Rowland, there is a certain factor somewhat resembling inertia which causes the lightning, once started, to follow sometimes an irregular path, similarly, for instance, as when a piece of paper is suddenly torn. Transmission lines and buildings of ordinary height surrounded by trees are not peculiarly subject to damage from lightning, because they cover a comparatively small portion of the earth, and are surrounded by objects of greater height, which offer a better path for the lightning discharge to the earth. They do, however, receive some discharge, and the damage which might be done can be very great. It is therefore, necessary to provide ample protection.

Generally speaking, the severe manifestations of lightning are confined to a relatively small area, which rarely exceeds in extent an area of about one square mile. It may be concluded from this that protective apparatus situated at certain points along the line will afford no protection to remote points.

Generally speaking, the broad requirements for lightning protection consist in supplying paths to ground for any charge which might accumulate on lines, or machinery from any cause whatever. The ideal arrester will cause excessive potential differences to be relieved instantaneously, and stop the flow of current, as soon as the potential has fallen to safe limits for the line. No one type of lightning arrester fulfills all requirements, and accordingly it is found expedient to use different types and combinations, in different situations, and under different conditions.

For the protection of electric circuits, grounded guard wires are best, and when the cost over the whole system would prove prohibitive, they should be confined to such localities as are peculiarly liable to suffer destructive discharges. Three ground wires are required for the best practicable protection. One of these should be placed on top, and in the middle of the line, and should be a heavy galvanized steel cable, and the other two, which should be heavy telegraph wires, are placed outside, and above the top side conductors. The ground wires should be earthed at every pole for the first 10 or 12 poles from the building, and at every second pole on the rest of the line. Graded resistance, or aluminum type lightning arresters should be installed on every feeder issuing from the station, and on the primary and secondary of every transformer, and a surge protector in the station, but choke coils having a large number of turns should not be used in the station, as they represent a possible source of danger.

Where from internal causes, such as flashing over a bushing or insulator, the arcing ground sends a series of oscillations through the circuit, it is necessary to provide an arrester which will continue to discharge the abnormal voltage for a sufficient period to permit the operator to locate and isolate the trouble. Half an hour is generally found to suffice for the period of an arrester, as this will give time to discover the point of trouble, where this is remote from the station.

Horn arresters placed along the line at various places will do much to protect insulators from puncturing or arcing across. These horn arresters should be adjusted to arc at something below the wet arc-over voltage of the insulators, and should be connected to earth direct. Only one phase per pole should be protected by a horn arrester, so that in the event of two horns arcing simultaneously, the earth resistance can be utilized to limit the discharge. Ground wires should not be grounded at poles carrying horn arresters.

Lightning rods, above wooden poles are an advantage. Graded resistance multigap, or aluminum arresters should be used on outgoing and incoming lines. Choke coils should be in the circuit just back of the arresters, which, in turn, are placed quite near the passages and are provided with disconnecting switches.

Multigap Arresters.—The general theory of the multigap arrester is as follows: When voltage is applied across a series of multigap cylinders, the voltage distribution is not uniform. The voltage distributes according to the capacity of the cylinders, both between themselves and also to ground, and the capacity of the cylinders to ground, results in the concentration of voltage across the gaps nearest the line. Fig. 622 shows the theoretical voltage gradient along an arrester. The voltage across the end gaps reaches a certain value. They arc across, passing the strain back to the other gaps, which in turn arc over until the spark has passed entirely across. The arrester in this manner arcs over at voltage much lower than would be required if the voltage distributed evenly. When the arrester has arced over, and current is flowing the voltage then does distribute evenly between the gaps, and is for this reason too low to maintain an alternating current arc. The arc, therefore, lasts only to the end of a half cycle, and then goes out. The maximum voltage per gap at which the arc will extinguish at the end of the half cycle depends to a great extent upon the metal of the cylinders. Thus some metals are more efficient than others in extinguishing the arc.

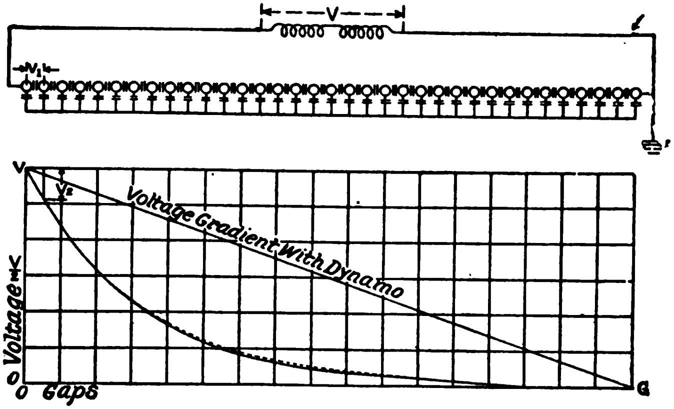


Fig. 622

LIGHTNING ARRESTER

When the voltage of an alternating current passes through zero, of course no current flows. Before the current flows in the reverse direction the voltage must again break through the dielectric. The voltage required to do this depends upon how much the dielectric has been weakened by the passage of the arc. The cooler the arc, the less the dielectric is weakened, and the higher will be the voltage required to reverse the arc. As the temperature of the arc depends upon the boiling point of the cathode metal, in very much the same way as the temperature of steam depends upon the boiling point of the water, metals with low boiling points are used for the lightning arrester cylinders, in order to keep down the arc temperature.

The use of resistance in a lightning arrester needs very careful consideration. Lightning does not readily pass through resistance, especially when in series with multigaps, and therefore series resistance should not be used. At the same time it is very desirable in some way to limit the current. This problem has at last been solved by use of a low shunt resistance, shunting a part of the gaps and so proportioned to divert the current from the gaps, after the discharge has passed the ground. Shunt resistance has been

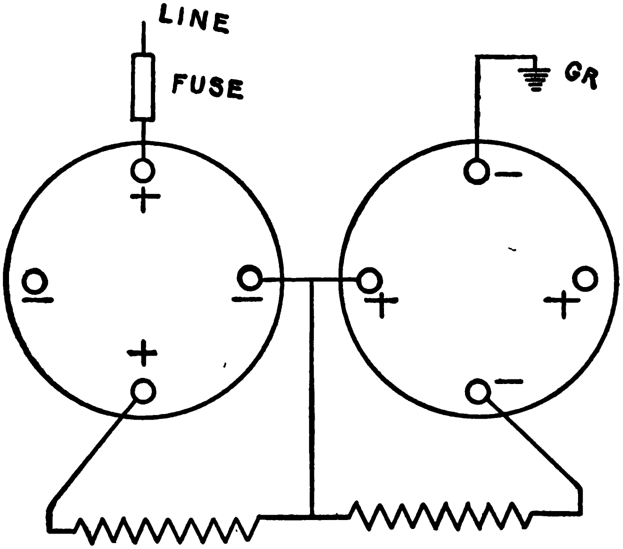


FIG. 623
STATION ARRESTER

used before, but never for this purpose, and was never made low enough to divert the arc in this way.

It is obvious, of course, that a discharge taking place through a high resistance will not relieve the line except in a case of the static. What happens, however, is something like this: When a surge of dangerous voltage rises, and before it reaches a danger point, the series gaps arc over. The series gaps then being practically short-circuited by the arc the voltage concentrates across the lowest division of the shunted gaps, and these at once also break down. The current is then limited by the medium resistance, and the voltage is concentrated across the second division of the arrester. If these gaps break down, the discharge is limited only by the low resistance, which should take care of most cases. If necessary, however, the voltage can "break back" in this way, and cut out all resistance. The number of gaps to rectify depends largely on the current that flows. In this arrester the number of gaps discharging increases as the limiting resistance decreases. The arrester will, therefore, operate and extingush the arc at the end of the half-cycle no matter which path the current takes.

Instructions for Installing 600 *Volt D. C. Aluminum Lightning Arresters.*—The principal elements of this arrester are two cells, each consisting of two concentric aluminum plates immersed in an electrolyte contained in a glass jar.

The outside plate of each cell should be the positive, and the inner one the negative, as indicated by the marking of the four studs on the porcelain cover, two studs supporting each plate.

In addition, station arresters are fitted with a balancing resistance in shunt with each cell and a series fuse; car arresters, with a series fuse as connecting link between the two cells. A diagram of connections is shown in Fig. 624.

To Fill the Arrester.—Unscrew the metal rings at the top of the jars and lift off the porcelain covers, with the aluminum plates attached, without removing the connection between the two units. Pour enough electrolyte into the jars to bring the level to about one inch from cover. Add ⅛ pint of oil to each jar.

In transferring the electrolyte, or oil from the carboy, or other container used for shipping, employ nothing but clean aluminum, or glass vessels and funnels. Take every precaution to prevent any dust or other material from getting into the electrolyte.

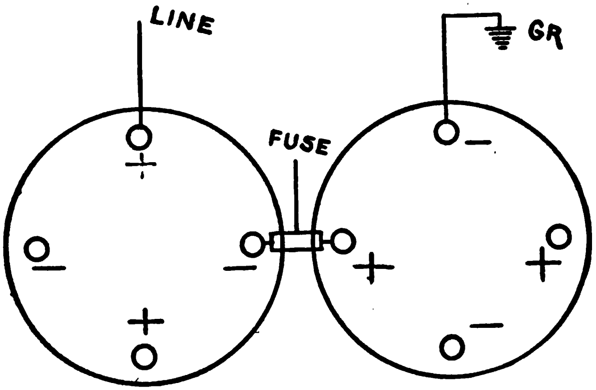


FIG. 624
CAR ARRESTER

Before connecting permanently to the circuit it is advisable to connect the arrester in series with five 120 volt incandescent lamps across the 600 volt circuit. The lamps will burn brightly for an instant and then rapidly diminish to darkness, thus indicating that the film is all right. If the lamps are dark at first, the circuit should be opened and closed, and a small snappy spark at the contact point will show that the circuit is complete and the film in proper condition. The lamps should then be removed and the cells connected directly to the circuit.

Connections.—These should be as short as possible between line and ground, and only to those points on which the terminals are placed when shipped. Use only the style of terminal furnished, as they afford no chance for a short circuit by swinging against the opposite terminal. In the case of pole arresters the test with series lamps, as described above, should be made before making the last connection, otherwise there may be a considerable flash due to an instantaneous current rush. The ground connection of these line arresters should be made directly to the ground bus, and driven pipe ground.

Operation.—If the arrester has stood assembled in its electrolyte for a month or more, when reconnected there will be a momentary rush of current which may amount to several hundred amperes. To avoid this current rush, use lamps in series as explained above.

It is preferable, however, when an arrester is to be left out of service for some time, to pour out the electrolyte and oil, wash the plates and jars with clean water and put the plates back in the jar. When replacing in service, make the usual test with lamps.

After operating for some time, arresters without balancing resistance, may divide the voltage unequally between cells, which is indicated by sparkling of the plates in one cell. In such cases the arrester should be removed from the circuit, and connected to a test circuit with a bank of five lamps in shunt with each jar; that is ten lamps from line to line with the middle point connected between cells. After operating this way for several hours remove the lamps. If sparkling has ceased, the arrester is ready to be placed in service.

After the arrester has been in operation for a short time, the electrolyte may become dark in appearance, but this condition is normal.

Inspection should cover answers to the following questions:

1. Are there any loose connections?
2. Is the level of the electrolyte at the proper height?
3. Are the positive plates worn off at the surface of the electrolyte?
4. Are the connecting leads as short as possible?
5. Does either cell sparkle?

Multigap Lightning Arresters for Alternating Currents.—These arresters, designed upon an elaboration of Prof. Elihu Thomson's fundamental patents, consist of a series of spark gaps shunted by graded resistances, but without series resistance. The advantages possessed by them are:

1. Uniform voltage discharge over a wide range of frequency due to graded resistance.
2. Shunting the dynamic current through resistance.
3. The "breaking back" action on low frequency surges.
4. Fuse in ground leg of non-grounded neutral systems.
5. Adjustable gap in each leg shunted by a fuse.
6. Metallic resistance rods of improved composition.
7. Durable knurled cylinders of special alloy.
8. General Electric standard multiplex connection.

When properly installed they will perform the following functions:

First. Prevent excessive rise of potential of a transitory nature between lines, as well as between lines and ground.

Second. Restrain the flow of electric current across the gaps, and extinguish the arc when normal potential is restored.

Third. Discharge high potentials covering a wide range of frequency.

The essential elements of the arrester are, a number of cylinders spaced with a small air gap between them and, placed between line and ground, and between line and line. In operation the multigap arrester discharges at a much lower voltage than would a single gap having a length equal to the sum of the small gaps.

In explaining the action of multigaps, there are three things to consider:

1. The transmission of the static stress along the line of cylinders.
2. The sparking of the gaps.
3. The action and duration of the dynamic current which follows the spark, and the extinguishment of the arc.

A spark may be defined as conduction of electricty by the air, and an arc as conduction of electricity by vapor of the electrode.

Distribution of Static Stress Along Cylinders.—The cylinders of the multigap arrester act like plates of condensers in series. This condenser function is the essential feature of its operation. When a static stress is applied to a series of cylinders between line and ground (Fig. 625), the stress is instantly carried from end to end. If the top cylinder is positive it will attract a negative charge on the face of the adjacent cylinder, and repel an equal positive charge to the opposite face, and so on down the entire row. The second cylinder has a definite capacity relative to the third cylinder and also to the ground; consequently the charge induced on the third cylinder will be less than on the second cylinder, due to the fact that only part of the positive charge on the second cylinder induces negative electricity on the third, while the rest of the charge induces negative electricity to the ground. Each successive cylinder, counting from the top of the arrester, will have a slightly smaller charge of electricity than the preceding one. This condition has been expressed as a "steeper potential gradient near the line."

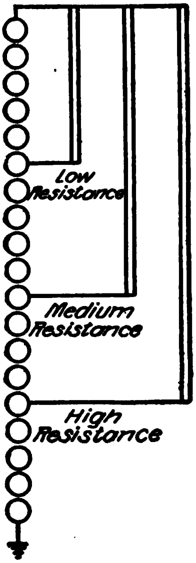


FIG. 625
ARRANGEMENT OF RESISTANCES

Sparking of the Gaps.—The quantity of electricity induced on the second cylinder is greater than on any lower cylinder, and its gap has a greater potential strain across it as shown by Fig. 626. When the potential across the first gap is sufficient to spark, the second cylinder is charged to line potential, and the second gap receives the static strain and breaks down. The successive action is similar to overturning a row of nine-pins by pushing the first pin against the second. This phenomenon explains why a given length of air gap concentrated in one gap requires more potential to spark across it, than the same total length made up of a row of multigaps. As the spark crosses each successive gap, the potential gradient along the remainder readjusts itself.

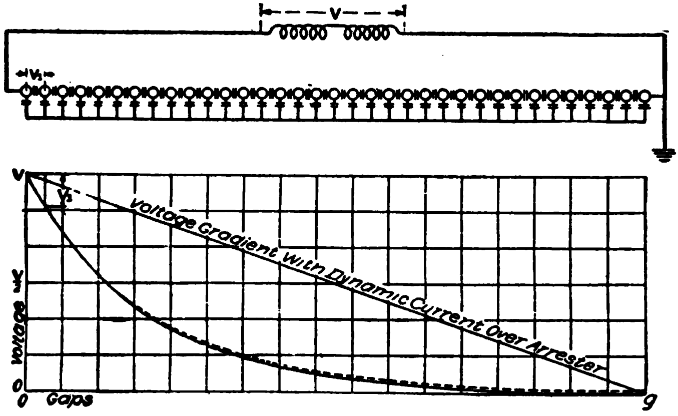


Fig. 626

DIAGRAM SHOWING CONDENSER ACTION OF CYLINDERS AND POTENTIAL GRADIENT FOR STATIC STRESS

How the Dynamic Arc is Extinguished.—When the sparks extend across all the gaps the dynamic current will follow if, at that instant, the dynamic potential is sufficient. On account of the relatively greater current of the dynamic flow, the distribution of potential along the gaps becomes equal, and has the value necessary to maintain the dynamic current arc on a gap. The dynamic current continues to flow until the potential of the generator passes through zero to the next half cycle, when the arc-extinguishing quality of the metal cylinders comes into action. The alloy contains a metal of low boiling point which prevents the reversal of the dynamic current. It is a rectifying effect, and before the potential again reverses, the arc vapor in the gaps has cooled to a non-conducting state.

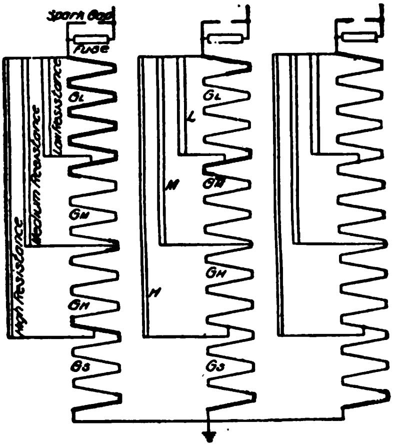


FIG. 627

CONNECTIONS FOR 33,000-VOLT Y SYSTEM WITH GROUNDED NEUTRAL

The Cumulative or Breaking Back Effect.—The graded shunt resistances (Figs. 627 and 628) give a valuable effect not brought out in the previous description, where the arrester is considered as four separate arresters. This is the cumulative or breaking back action.

When a lightning strain between line and ground takes place, the potential is carried down the high resistance, H, to the series gaps, GS, and the series gaps spark over. Although it may require several thousand volts to spark across an air gap, it requires relatively only a few volts to maintain the arc which follows the spark. In consequence, when the gaps GS spark over, the lower end of the high resistance is reduced practically to ground potential. If the high resistance can carry the discharge current without giving an ohmic drop sufficient to break down the shunted gaps GH, nothing further occurs—the arc goes out. If, on the

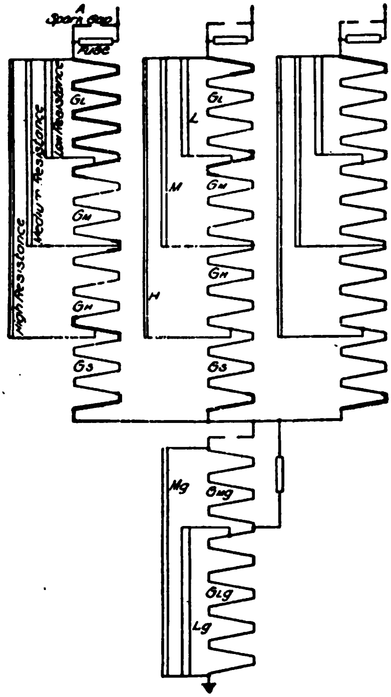


FIG. 628

CONNECTIONS FOR 33,000-VOLT DELTA OR UNGROUNDED Y SYSTEMS contrary, the lightning stroke is too heavy for this, the potential strain is thrown across the shunted gaps, GH, equal in number to the previous set. In other words, the same voltage breaks down both of the groups of gaps, GS and GH, in succession. The lightning discharge current is now limited only by the medium resistance, M, and the potential is concentrated across the gaps, GM. If the medium resistance cannot discharge the lightning, the gaps GM spark, and the discharge is limited only by the low resistance. The low resistance should take care of most cases, but with extraordinarily heavy strokes and high frequencies, the discharge can break back far enough to cut out all resistance. In the last step the resistance is relatively low in proportion to the number of shunt gaps, GL, and is designed to cut out the dynamic current instantly from the gap, GL. The illustration (Fig. 631) of the 2,200 volt arrester shows that the low resistance actually performs this function. This breaking back effect is valuable in discharging lightning of low frequency, in a manner better than has been obtained before.

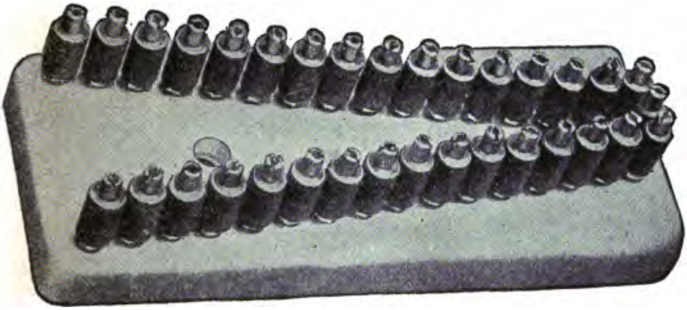


FIG. 629

"V" UNIT OF MULTIGAP LIGHTNING ARRESTERS

After the spark passes, the dynamic arcs are extinguished in the reversed order. The low resistance, L, is proportioned so as to draw the dynamic arcs instantly from the gaps, GL. The dynamic current continues in the next group of gaps, GM, until the end of the half cycle of the generator wave. At this instant the medium resistance, M, aids the rectifying quality of the gaps, GM, by shunting

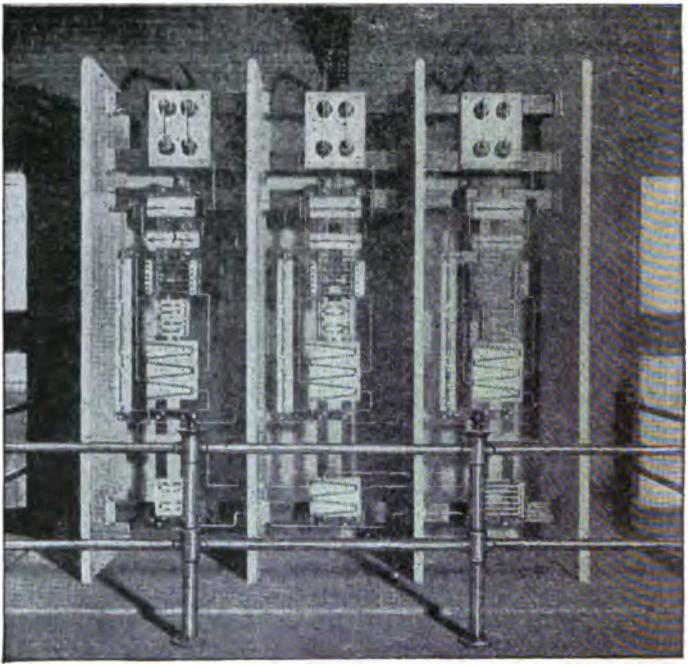


Fig. 630
INSTALLATION OF A 12,000-VOLT, THREE-PHASE, MULTIGAP LIGHTNING ARRESTER IN THE GARFIELD PARK SUB-STATION OF THE WEST CHICAGO PARK COMMISSION

out the low frequency dynamic current of the generator. On account of this shunting effect the current dies out sooner in the gaps, GM, than it otherwise would. In the same manner, but to a less degree, the high resistance, H, draws the dynamic current from the gaps, GH. This current now being limited by the high resistance, the arc is easily extinguished at the end of the first one-half cycle of the generator wave.

"V" Unit for Multigap Arresters.—The High-voltage Multigap Arrester is made up of "V" units (see Fig. 629), each unit consisting of gaps between knurled cylinders, and connected together at their ends by short metal strips. The base is of porcelain, which thoroughly insulates each cylinder, and insures the proper functioning of the multigaps.

Cylinders.—The cylinders are made of an improved alloy that contains metal of low boiling point which gives the rectifying effect, and metals of high boiling point which cannot vaporize in the presence of the one of low boiling point. The cylinders are heavily knurled. As the arc plays on the point of a knurl it gradually burns back and when the metal of low boiling temperature is used up, the gap is increased at that particular point. The knurling therefore, insures longer life to the cylinder, by forcing successive arcs to shift to a new point. When worn along the entire face, the cylinder should be slightly turned.

Resistance Rods.—The low resistance section of the graded shunt is composed of rods of a new metallic alloy. These rods have large current-carrying capacity, and practically zero temperature coefficient up to red heat.

The medium and high resistance rods are of the same standard composition previously used. The contacts are metal caps shrunk on the ends; the resistances are permanent in value and the inductance is reduced to a minimum. The rods are designed with a large factor of safety, and have sufficient heat absorbing capacity to take the dynamic energy following transitory lightning discharges. They are glazed to prevent absorption of moisture, and surface arcing.

DIFFERENCE BETWEEN ARRESTER FOR GROUNDED Y AND NON-GROUNDED NEUTRAL SYSTEMS.

The connection for a three-phase arrester, 33,000 volts between lines, are shown in the illustrations (Figs. 627 and 628). One illustration (Fig. 627) shows the design for a thoroughly grounded Y system and the other for a non-grounded neutral system. The latter (Fig. 628) includes delta, ungrounded Y, and Y systems grounded through a high resistance.

The difference in design lies in the use of a fourth arrester leg between the multiplex connection and ground, on ungrounded systems. The reason for introducing the fourth leg is evident. The arrester is designed to have two legs between line and line. If one line became accidentally grounded, the full line potential would be thrown across one leg, if the fourth or ground leg were not present. On a Y system with a grounded neutral, the accidentally grounded phase causes a short circuit of the phase, and the arrester is relieved of the strain by the tripping of the circuit breaker. Briefly stated, the fourth or ground leg of the arrester is used when, for any reason, the system could be operated, even for a short time, with one phase grounded.

Multiplex Connection.—The multiplex connection consists of a common connection between the phase legs of the arrester above the earth connection, and provides an arrester better adapted to relieve high potential surges between lines than would otherwise be possible. Its use also economizes greatly in space and material for delta and partially grounded or non-grounded Y systems.

Fuse Auxiliaries.—The practice of introducing an auxiliary adjustable gap between each line wire and its corresponding leg of the arrester has been discarded in the new design, with marked increase in the *sensitiveness* of the arrester. As the gap is necessary, under certain abnormal conditions, it is left on the arrester, but short circuited by a fuse so that it comes into service only when the fuse blows on account of an arc between phase and ground, or some similar extremely severe continued strain. The sensitiveness is also greatly increased by the addition of a similar shunting fuse around the adjustable gap in the ground leg of the arrester. The ground leg is necessary only when there is an accidental ground of a phase and, ordinarily the increased sensitiveness is maintained continually.

Location.—Ample wall space should be provided and plenty of room in front should be left for the operator. The arresters should be placed as near as possible to where the lines enter the buildng. The following minimum separation distances have proved entirely satisfactory.

TABLE GIVING PROPER SPACE BETWEEN LIGHTNING ARRESTERS AND SETTING OF ADJUSTABLE GAP.

Max. Volts	Distance in Inches Between Live Parts of Adjacent Phases	Minimum Distance Between Centers (See Note)	Inches of Gap
7,600	8″	28″	¼
12,250	8″	28″	⅜
13,500	8″	33″	⅜
17,000	10″	35″	⅜
22,000	12″	37″	½
27,000	18″	48″	½
32,000	22″	52″	⅝
37,000	26″	56″	¾

NOTE—If barriers are used the width of barriers should be added to distances given.

It is advisable to locate arresters in a dry place, and before assembling them the wooden supports, insulators, etc., should be thoroughly dried of all moisture which may have collected during transportation.

The adjustable spark gap on these arresters is shunted by a fuse. This fuse blows under certain conditions and cuts in the added protection of the gap. The settings of this gap for the various arresters should be as already explained.

Voltage Range of Arresters.—Lightning arresters of the form described have been designed for voltages from 5,700 to 37,000. For lower voltages, down to 300 volts, alternating current, the arresters are of slightly different design, havng only two resistance rods. For 300 volts and less no resistance is necessary, as the voltage is so low that the arc cannot hold. These arresters, therefore, consist simply of spark gaps.

LOW VOLTAGE ARRESTERS—FORMS F1 AND F2.
300 TO 5,700 VOLTS.

The 2,200-volt (Figs. 631 and 634) arrester consists of one unit having fourteen cylinders, nine of which are shunted by a low resistance and eleven by a high resistance. As in the case of the high voltage arresters, the grading of resistance provides *selective paths* for discharges. Its action and advantages are therefore similar to those of the high-voltage arrester. Accumulated static charges pass off across the high resistance, and two gaps. High frequency discharges pass across all the gaps; discharges of moderate frequency across the low resistance, and four gaps. The low resistance is so proportioned to the number of shunted gaps that the high frequency discharge across these gaps is not followed by the dynamic current; the dynamic shunting at once to the low resistance. The discharge takes place over all the gaps, but the arcs between the gaps shunted by the low resistances are very small compared with the bright arcs between the last four gaps. The static discharge passes through all the gaps, while the half wave of dynamic current following the static is shunted part of the way by the resistance.

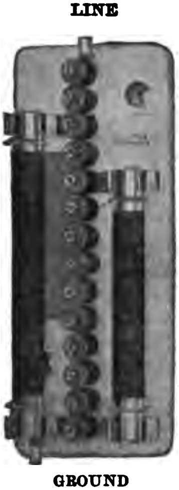


FIG. 631
FORM F1, 2,200-VOLT MULTIGAP ARRESTER FOR STATIONS

An oscillogram of this phenomenon is shown in Fig. 632. The only current in the shunted gaps is the current of static discharge. It should be noted, however, that the current shown is not a measure of the true current, as the oscillograph cannot respond to currents of such high frequency.

It should be here explained that the oscillograph is a device consisting of a galvanometer of strong field and high frequency of vibration, and is used for recording waves of alternating current.

This arrester is designed to operate across 2,200 volts. It is used, however, from each line to ground, giving, thus connected, sufficient protection, and being always able to handle a discharge when one line is grounded. It is built to be used single-pole, but by placing two or three in the same box, becomes double-pole or triple-pole.

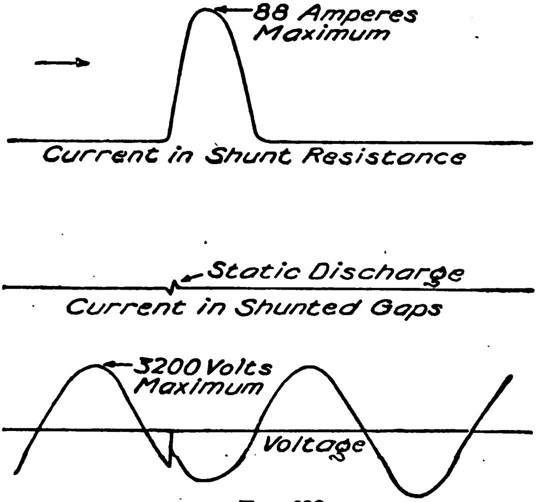


Fig. 632

OSCILLOGRAPH CURVES SHOWING LIGHTNING ARRESTER ACTION

The 1,000-volt arrester is the same in design, but has only one gap between the high resistance rod and line.

The 3,000-volt arrester (see Fig. 633) is based on the same general principle as the 2,200-volt arrester, differing from it mainly in having two additional gaps to take care of the higher voltage.

The 2,200-volt arrester (Fig. 634) is used in various combinations to form arresters of higher voltage.

Low-Voltage Lightning Arresters.—For low-voltage, alternating-current circuits up to 300 volts the lightning arrester shown in Fig. 635 is used. This type meets the requirements for the protection of low voltage circuits such as transformer secondaries, motors, series arc lamps, etc. These arresters are made in single, double and triple-pole units.

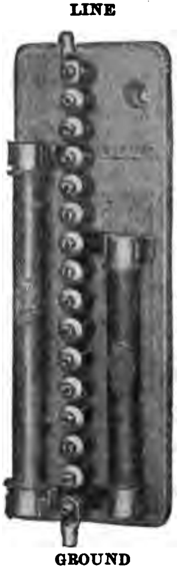


FIG. 633

FORM F2, 3,000-VOLT MULTIGAP ARRESTER FOR STATIONS

Protection of Cable Systems.—It is frequently necessary, and desirable for circuits to dip underground when passing through cities, under rivers, etc., and in these cases some form of metal covered cable is generally used. Resonance invariably produces high potentials at the junction of overhead, and underground lines, and these potentials are often of sufficient value to break down the insulation of the cables, and also the insulation of apparatus installed on the system.

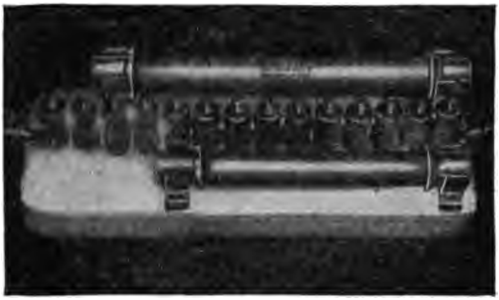


FIG. 634
2,200-VOLT, FORM F1, LIGHTNING ARRESTER, DISCHARGING AND SHUNTING THE DYNAMIC CURRENT

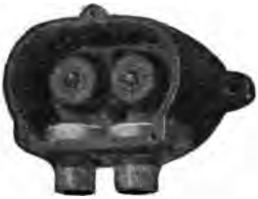


FIG. 635
SINGLE-POLE ARRESTER

Whenever lines contain both inductance, and capacity in appreciable quantities, high voltages, which endanger the insulation of the whole system, and which it is impossible to detect on ordinary switchboard instruments may exist. Abnormal voltages are therefore often found in circuits containing a combination of underground, and overhead circuits and in underground transmission lines.

Constant Current Arresters.—For constant current lighting circuits, horn arresters with resistances are recommended. It is advisable to place these arresters in the station on each outgoing line. When cables are used, the arrester should be placed on the pole where the cable joins the overhead wires. Fig. 637 shows the appearance of a horn lightning arrester.

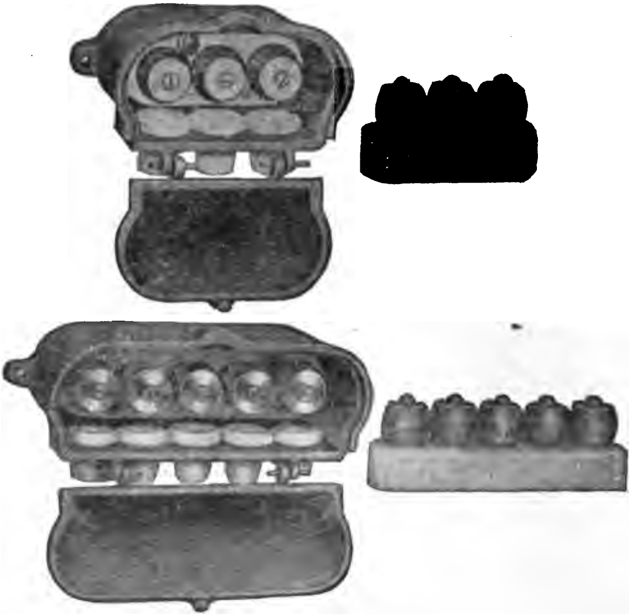


FIG. 636
DOUBLE-POLE AND TRIPLE-POLE 300-VOLT ARRESTERS

Disconnecting Switches.—Lightning arresters with disconnecting switches are desirable in order that they may be disconnected from the line for proper inspection, adjustment, cleaning, etc., without opening the line circuit.

The disconnecting switches, except the 2,500-volt switches, are of the post insulator type. The 2,500-volt switches are single-blade, front connected, and are mounted directly on marble bases. The post insulator switches are arranged for mounting on flat surfaces.

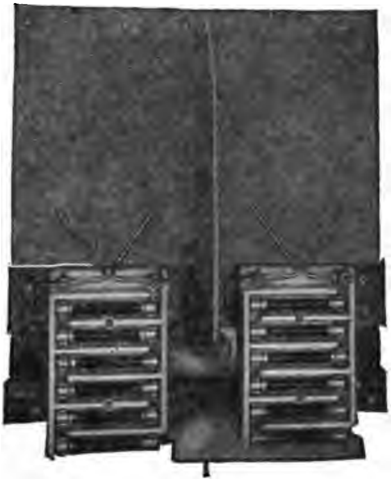


FIG. 637

HORN ARRESTER FOR CONSTANT CURRENT CIRCUITS

Choke Coils.—The proper selection of choke coils is an important feature of lightning protection. Choke coils should be used with lightning arresters except, when the arresters are used to protect cable systems.

Three types of choke coils are shown in Figs. 639 and 640. The 4,600-volt coil is made of insulated wire, wound on wooden core supported by iron feet. The 6,000-volt coil is made of insulated wire and is mounted on marble base. For voltages above 6,000 the "hour glass" type with air insulated turns is used. With this type the coil is mounted on a wooden, slate or marble base.

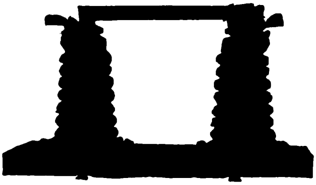


FIG. 638
POST TYPE INSULATOR DISCONNECTING SWITCH

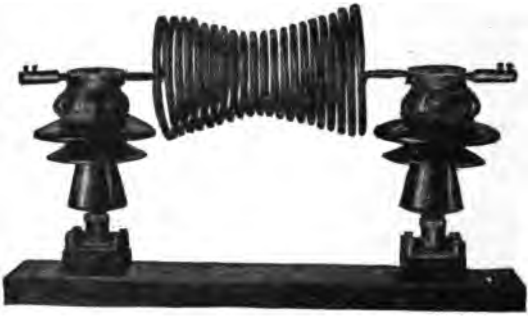
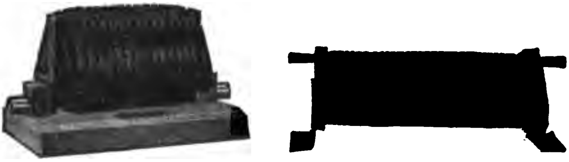


FIG. 639
HOUR GLASS TYPE—CHOKE COIL 15,000-35,000 VOLTS



6,000 VOLTS 4,600 VOLTS

FIG. 640
LOW VOLTAGE CHOKE COILS

The "hour glass" type has the following advantages on high voltages.

1. Should there be any arcing between adjacent turns, the coils will reinsulate themselves after the discharge.
2. They are mechanically strong, and sagging is prevented by tapering the coils toward the center turns.
3. The insulating supports can best be designed for the strains that they have to withstand.

In providing lightning arresters the following points should be considered:

1. What is the normal line to line voltage?
2. How many sets of transmission lines are there?
3. Is the system single-phase, two-phase, or three- phase; or three-phase, four wire?
4. Is the system delta connected; Y connected, neutral non-grounded; or Y connected, neutral grounded?
5. If single-phase, is the neutral grounded?
6. Are switches to be furnished with the arrester?
7. If so, are they to be double-blade or single-blade?
8. If double-blade switches are required, state the current-carrying capacity of the line switch.
9. Are choke coils to be furnished? If so, state their ampere capacities and the number desired.
10. The number of switch hooks to be furnished.
11. If the line is partly overhead, and partly underground, submit a rough sketch that shows where the underground portion is located with reference to the stations and the remainder of the line.

DIRECT CURRENT LIGHTNING ARRESTERS.

The Type M Form D-2 arrester (Fig. 641) has been the standard for direct current circuits for several years, and is furnished for lighting and power circuits of from 60 to 375 volts, and for railway and power circuits of from 250 to 1,800 volts.

The present form of arrester is somewhat longer and narrower than the earlier types, and the spark gap, and non-inductive resistance are in a straight line, thus forming a direct path for the discharge, and reducing to a minimum the possibility of short circuit in the box in case of excessively heavy lightning discharges. One of the valuable features of the MD-2 arrester is the fact that all parts can be readily inspected on removing the cover of the porcelain enclosing box (Fig. 642) and a glance will show if the arrester is in proper condition for the next storm. The gap is surrounded by a strong electro-magnet, which immediately blows out the dynamic arc through the chute after the lightning discharge has passed.

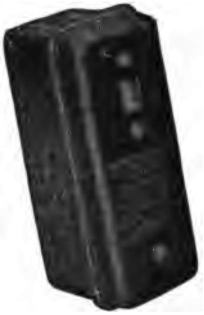


FIG. 641
DIRECT CURRENT ARRESTER, TYPE M, FORM D-2

The gaps on arresters up to 850 volts are adjusted to .025 inch, and on higher voltages to .094 inch. These arrangements have been found to afford excellent protection to the insulation of the equipments, due to the low breakdown points.

The spark gap terminals are threaded, and attached to the lid of the box, thus affording a ready method of adjustment, positive grip on the terminals, and easy access for examination.

Ground Connections.—In all lightning arrester installations it is of utmost importance to make perfect ground connections, as a large majority of lightning arrester troubles can be traced to the lack of this precaution. It has been customary to ground a lightning arrester by means of a large metal plate buried in a bed of charcoal, at a depth of six or eight feet in the earth.

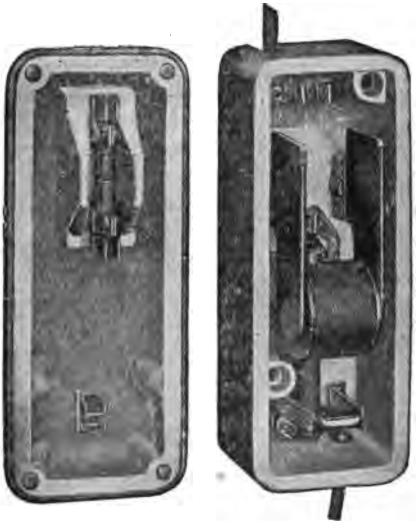


FIG. 642
DIRECT CURRENT LIGHTNING ARRESTER—INTERIOR

A more satisfactory method of making a ground is to drive a number of 1-inch iron pipes six or eight feet into the earth at several points about the station, connecting all these pipes together by means of copper wire or preferably copper strip. A quantity of salt should be placed around each pipe at the surface of the ground and the ground thoroughly moistened with water. It is advisable to connect the pipes to the iron frame work of the station,

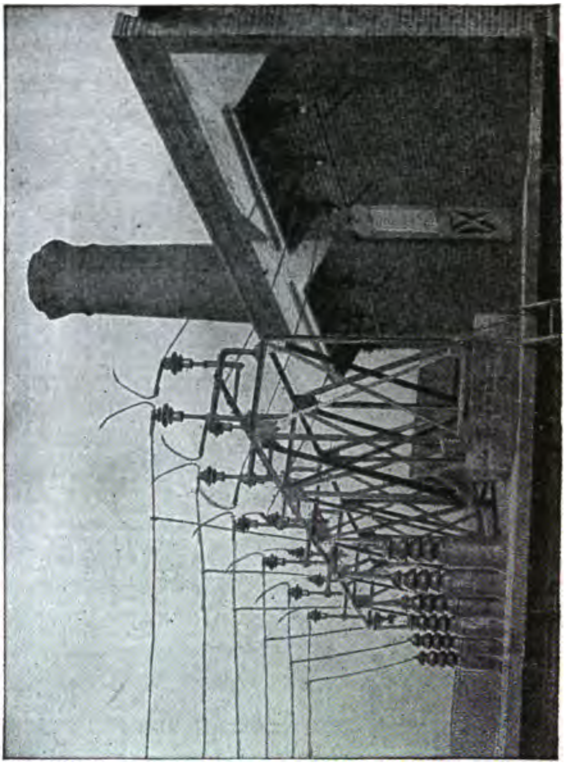


FIG. 643

HORN GAP INSTALLATION FOR 35,000 VOLT ALUMINUM LIGHTNING ARRESTERS, SCHENECTADY POWER CO., SHOWING ROOF ENTRANCES TO STATION AND WALL ENTRANCES TO LIGHTNING ARRESTER TOWER. ONE SET OF ARRESTERS DISCONNECTED and also to any water mains, metal flumes, or trolley rails that are available.

For the station of ordinary size the following recommendation is made. Place three earth-pipes equally spaced near each outside wall, making twelve altogether, and place three extra pipes spaced about six feet apart at a point nearest the arrester.

When plates are placed in streams of running water, it is much better for them to be buried in the mud along the bank, than to lie in the stream. Streams with rocky bottoms are to be avoided except as a last resort.

Whenever plates are placed at any distance from the arrester it is advisable to drive a pipe in the earth directly beneath the arrester, thus making the ground connections as short as possible. Earth plates at a distance cannot be depended upon. Long ground wires in a station cannot be depended upon, unless a lead is carried to the multiple pipe-earths described above.

In view of the fact that it is advisable to occasionally examine the ground connections to see that they are in proper condition, it is desirable to lay out the exact plans of the location of the ground plates, ground wires, or pipes, with a brief description of them, so that at any time the data may be referred to.

From time to time the resistance of the ground connections should be measured to determine their condition. This is very easily done when pipe grounds are installed, as the resistance of one pipe can be accurately determined, when three or more pipes are used. The resistance of a single pipe ground in good condition has an average value of about 15 ohms. A simple and satisfactory method of keeping account of the condition of the earth connections is to divide the pipe-earths into two groups, and connect each group to the 110-volt lighting circuit, with an ammeter in series. If there is a flow of about 20 amperes the conditions are satisfactory, provided the pipe-earths are properly distributed around the station.

ALUMINUM LIGHTNING ARRESTERS.

The design of the aluminum arrester is based on the characteristics of a cell consisting of two aluminum plates on which has been formed a film of hydroxide of aluminum, immersed in a suitable electrolyte. This film is formed on the aluminum plates by a series of chemical and electrochemical treatments at the factory.

Valve Action.—Up to a certain critical voltage this hydroxide film has the property of insulating, or rather opposing the flow of current and is, therefore, closely analogous to a counter-electromotive force. Up to this critical voltage only a small leakage and charging current can flow, but during any rise above this voltage the current flow through the cell is limited only by the actual resistance of the electrolyte, which is very low. The action is comparable to that of the well-known safety valve of a steam boiler by which the steam is confined until the pressure rises to a given value, at which point the valve opens and releases the excess pressure. This action of the aluminum cell is also closely analogous to that of a storage battery on direct current. Up to about two volts per cell, impressed, the storage battery, when charged, opposes an equal counter-electro-motive force, shutting off the flow of current; but for voltage above this value the current is limited only by the internal resistance of the cell. This characteristic makes the aluminum cell ideal as a means of discharging abnormal potentials, or surges in electric circuits. It practically prevents the flow of current at operating voltages, but instantly short circuits such abnormal portions of a potential wave, or surge, as would be dangerous to the insulation of the system.

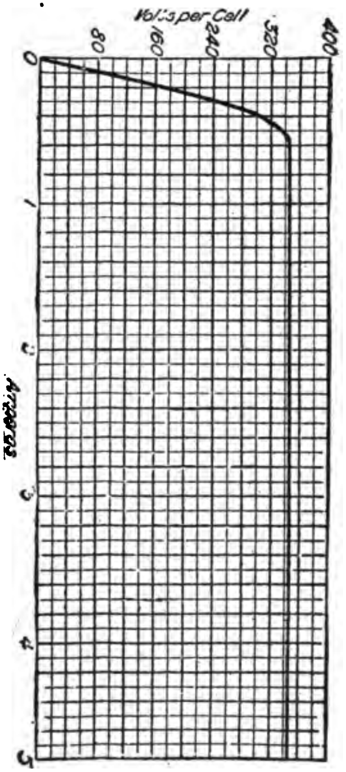


Fig. 644

VOLT-AMPERE CHARACTERISTIC CURVE OF ALUMINUM CELL

A volt-ampere-characteristic-curve of the aluminum cell on alternating current is shown in Fig. 644. The data for this curve was taken with an oscillograph. It should be noted that the critical voltage, alternating current, is slightly above 340 volts. This cut gives the discharge rate only up to 5 amperes, in order to better illustrate the normal and critical voltage points. Above this value the discharge rate depends almost entirely upon the internal resistance of the electrolyte. This resistance is such that at double the normal operating voltage, or 600 volts per cell, the current discharge is six hundred, to one thousand amperes for a brief time. This rate of discharge represents a quantity of electricity several times greater than the quantity liberated by an ordinary induced lightning stroke.

Condenser Action.—Besides the valve action described above there is another characteristic of the cell of great importance. The thin insulating film of aluminum hydroxide between the conducting aluminum and the conducting electrolyte acts as a dielectric and the cell, therefore, is an elecstatic condenser. A condenser of this type makes an ideal path for high frequency lightning discharges. With these arresters, for instance, 10,000 cycles, which is not an unusual frequency for lightning disturbances, would discharge almost 100 amperes without any rise in voltage.

Due to this capacity, these aluminum arresters cannot be connected permanently across alternating voltage. The charging current at normal frequency (about .5 amp.) would in time heat the electrolyte. In every case, therefore, spark gaps set to arc over at slight increase of voltage, insulate the arrester from the line.

Film Dissolution.—Another characteristic of the aluminum cell is the dissolution of a part of the film when the plates stand in the electrolyte, and the cell is disconnected from the circuit. The film is presumably composed of two parts; one part is hard and insoluble, and apparently acts as a skeleton to hold the more soluble part. When a cell, which has stood for some time disconnected, is reconnected to the circuit, there is a momentary rush of current, which replaces the part of the film which has dissolved. All electrolytes dissolve the film, the extent of the dissolution depending upon the length of time the film is in the electrolyte, the electrolyte used, and its temperature. It is neces-

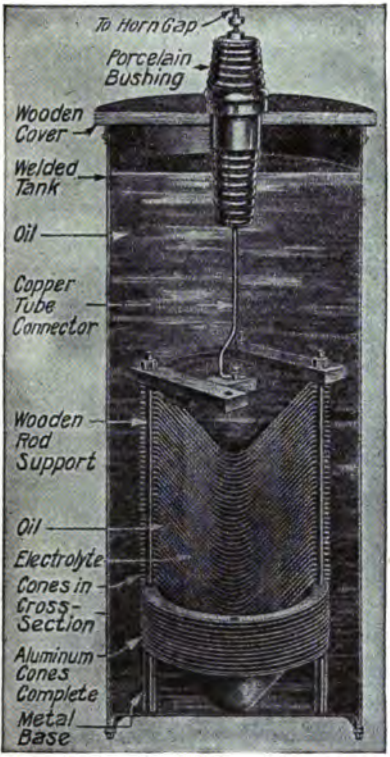


FIG. 645

CROSS SECTION OF ALUMINUM LIGHTNING ARRESTER sary to charge the cells from time to time to prevent the initial rush of dynamic current causing trouble. By keeping the films formed at all times, the initial rush of current is prevented, and the ultimate temperature rise in case of continued discharge of the arrester is minimized. The ability of the arrester to take care of discharges lasting for any considerable length of time, therefore, depends upon the conditon of the arrester film. When the cells, in commercial use, are allowed to stand for not more than a day or two, the film dissolution, and initial current rush is negligible. Suitable means are provided with the arresters for connecting them directly across the line. This is a very simple operation, and thus the film is kept in good condition.

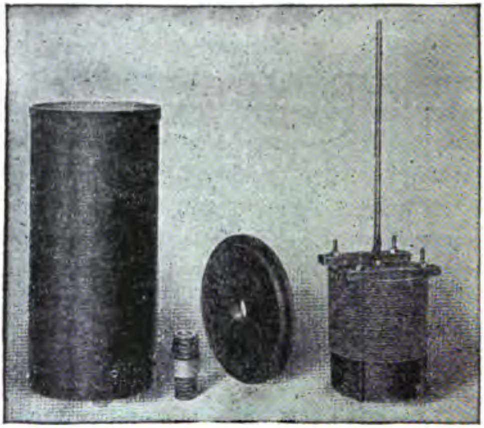


FIG. 646

PARTS OF 15000 VOLT ALUMINUM LIGHTNING ARRESTER

In very warm climates it is sometimes advisable to take special precaution to keep the cells normally cool.

Design.—The aluminum lightning arresters for alternating current circuits from 1,000 to 110,000 volts consist essentially of inverted aluminum cones, placed one above the other in stacks, and insulated with a vertical spacing of about .3 inch. An electrolyte partially fills the space between adjacent cones, so forming aluminum cells connected in series. The stack of cones with the electrolyte between them is then immersed in a tank of oil. The electrolyte being heavier than the oil remains between the

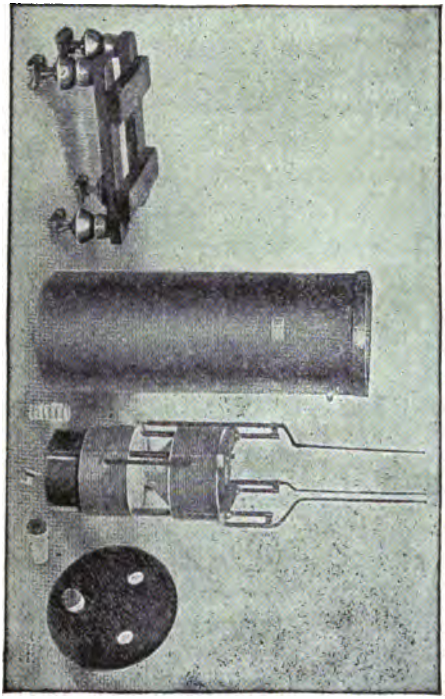


FIG. 647

PARTS OF 4600 VOLT THREE-PHASE ALUMINUM LIGHTNING ARRESTER aluminum cones. The oil improves the insulation between cones, prevents evaporation of the solution and, due to its heat absorbing capacity, enables the arresters to discharge continuously for long periods, a very valuable feature of these arresters. The tanks are of steel with welded seams.

The general arrangement of the cells is shown in Figs. 645, 646 and 647.

QUESTIONS AND ANSWERS.

935. How are switchboards made up?

Ans. They are built up of panels of slate or marble supported by frames of angle iron.

936. How are the different panels designated?

Ans. Some are for motor control, others for dynamo running, others for operating the outer circuit, and others for charging storage batteries.

937. Is a knowledge of switchboards an important matter?

Ans. It is, and every engineer should especially study those in his own station.

938. What is the regular equipment of a D. C. switchboard having a capacity of from 250 to 6,500 amperes?

Ans. One carbon-break or magnetic blow-out circuit breaker with telltale.

One illuminated dial ammeter with shunt.
One hand wheel and chain for operating rheostat.
One receptacle for voltmeter plug.
One S. P. S. T. field switch.
One S. P. S. T. main switch.
One recording watt-hour meter.

939. What is meant by the abbreviations S. P. S. T.?

Ans. Single Pole Single Throw.

940. What does D. P. D. T. mean in speaking of switchboards?

Ans. Double Pole Double Throw.

941. What is meant by T. P.?

Ans. Triple pole. It opens every circuit of a three-phase system.

942. Is it good practice to place a main switch at the machine?

Ans. It is best.

943. Why?

Ans. So that the cables from generator to board may be cut off at the generator.

944. What is an equalizer?

Ans. It is a cable running along from machine to machine, and connecting the functions of series field and brush on all the machines, but does not connect with switchboard.

945. What kind of a break has the field switch?

Ans. A carbon break.

946. Describe the action of a field switch.

Ans. Just before it opens it makes contact with an extra clip, and puts a resistance on as a shunt around the field coils.

947. If this were not done what would be the consequences?

Ans. The fields would act as a spark-coil and the insulation be damaged.

948. When it is desired to throw a generator in parallel with other generators already running what is the proper method of procedure?

Ans. First. Close main and equalizer switches near the machine.

Second. Close field switch on panel.

Third. Close circuit breaker.

Fourth. Insert potential plug in receptacle and regulate voltage.

Fifth. When proper voltage is obtained close the other main switch on panel.

949. What is meant by voltage?

Ans. Electric pressure, or potential.

950. What is a volt?

Ans. The unit of pressure.

951. What is a voltmeter?

Ans. An instrument that indicates the voltage.

952. What is an ohm?

Ans. The unit of resistance.

953. Give a brief definition of Ohm's law?

Ans. The electromotive force equals the resistance multiplied by current intensity.

954. What is an ampere?

Ans. It is the unit of volume, or quantity-time unit for measuring the rate of flow of an electric current.

955. What is a coulomb?

Ans. It is an ampere-second. A coulomb equals the flow of an ampere of current past a given point each second of time.

956. What is an ammeter?

Ans. An apparatus for measuring current rate.

957. What is the meaning of the word watt as used in electrical work?

Ans. A watt is the unit of work. It equals volts×amperes.

958. What is the function of the wattmeter?

Ans. To record the watt-hours of work.

959. What is a kilo watt (K. W.)?

Ans. 1,000 watts.

960. Expressed in mechanical horse-power, what is one K. W. equal to?

Ans. 1000÷746=1 1/3 H. P.

961. What is a field rheostat?

Ans. An apparatus for controlling the current output.

962. What is the function of a transformer?

Ans. To transform the current from a higher to a lower voltage, or from A. C. to D. C.

963. What is meant by synchronism of electric machines?

Ans. When the maximum value of the E. M. F. in each machine occurs at exactly the same instant of time, the machines are in synchronism.

964. What is meant by the exciter panel of a switchboard?

Ans. It is the panel that is equipped with the necessary switches, etc., for connecting the small exciter dynamo with the other generators in the station.

965. What is a sub-station?

Ans. It is the connecting link between the transmission line, and the trolley wire or third rail.

966. When A. C. is generated at the power station, and D. C. is used on the line, how is it accomplished?

Ans. The A. C. is changed to D. C. by rotary converters at the sub-station.

967. What is meant by frequency?

Ans. The number of times the current reverses per second.

968. What is the usual frequency for railway motors?

Ans. 25 is the standard.

969. What is a frequency changer?

Ans. A machine which receives current at one frequency and delivers it at another frequency.

970. What apparatus is used in an A. C. to D. C. substation?

Ans. Step down transformers, rotary converters, and A. C. incoming and D. C. outgoing switchboards.

971. What is the proper procedure for placing rotary converters in service?

Ans. After the machine has been started from the A. C. ends, and builds up with the proper polarity, first close the equalizer switch (on machine)—second, close circuit breaker on panel—third, insert potential plug in receptacle and regulate voltage—fourth, when the proper voltage is obtained, close positive switch (on panel).

972. What will be the result if the rotary builds up with polarity reversed?

Ans. The voltmeter will swing back of zero.

973. How may the polarity be corrected?

Ans. By means of the four-pole, double-throw field break-up reversing switch mounted on the converter.

974. Describe an oil switch.

Ans. It is a switch similar in its action to other switches, with the exception that its mechanism is immersed in a small tank of oil.

975. What advantage is gained thereby?

Ans. Reliability of action in opening or closing a circuit.

976. Mention another advantage gained by the use of the oil switch and oil circuit breaker.

Ans. It has made safely possible the transmission and use of high-tension currents of electricity.

977. What is a circuit breaker?

Ans. It is a switch so designed as to be capable of frequently opening the circuit carrying its full current without any damage to itself.

978. What is a galvanometer?

Ans. An instrument consisting of a coil of wire carrying the current to be tested, and a magnet, the two being arranged so that one can be deflected.

979. Describe the Thompson type of galvanometer.

Ans. The coil of wire is stationary, and the light magnetic needle is suspended by a silk thread.

967. Describe the D'Arsonval galvanometer.

Ans. In this type the small light coil of wire is suspended by a fine bronze wire between the poles of a stationary magnet.

968. How are the readings taken from these instruments?

Ans. From a circular scale, over which the needle of the instrument swings.

980. What is a lightning discharge?

Ans. An equalization of potential between the earth, and either clouds, or saturated atmosphere.

981. What path does the discharge generally follow?

Ans. The path of least resistance.

982. What are the general requirements for protection of electric stations from lightning?

Ans. The supplying of paths to ground for any charge which might accumulate on lines or machinery.

983. What is the general theory of the multi-gap lightning arrester?

Ans. When voltage is applied across a series of multigap cylinders, the voltage distribution is not uniform, but is governed by the capacity of the cylinders, both between themselves, and also to ground, which results in the concentration of voltage across those gaps nearest the line.

984. What are the principal elements of a 600 volt D. C. aluminum lightning arrester?

Ans. Two concentric aluminum plates immersed in an electrolyte contained in a glass jar, the outside plate of each cell being positive, and the inner one negative.

985. Describe the multigap lightning arrester for A. C.

Ans. It consists of a series of spark gaps shunted by graded resistances, but without series resistance.

986. Describe briefly the aluminum lightning arrester.

Ans. It consists of two aluminum plates on which has been formed a film of hydroxide of aluminum, immersed in a suitable electrolyte.

Current Distribution

Divided Circuits.—Currents of electricity, although they have no such material existence as water or steam, still obey the same general law; that is, they flow and act along the lines of least resistance. If a pipe extending to the top of a ten-story building had a very large opening at the first floor, it would be impossible to force water to the top floor. All the water would run out at the first floor. If the opening at the first floor were small only a part of the water would escape through it, some would reach the top of the building. The flow of water in each case is inversely proportional to the resistance offered to it by the different openings.

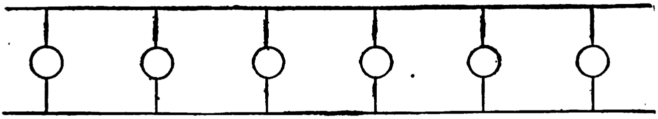


FIG. 648

The same thing is true of currents of electricity. Where several paths are open to a current of electricity the flow through them will be in proportion to their conductivities, which is the inverse ratio of their resistances. As an illustration, the current flow through all of the lamps, Fig. 648, is the same, because each lamp offers the same resistance. But if we arrange a number of lamps as in Fig. 649, the lamps in series will offer twice as much resistance as the single lamps, and will receive but half the current of the single lamp. In Fig. 650 we have still another arrangement. The lamp A limits the current which can flow through B and C, and that current which does flow divides between B and C in proportion to their conductivities. If B has a resistance of 110 ohms and C 220 ohms, then B will carry two parts of the current and, C only one. The combined resistance of all lamps, Fig. 648, equals the resistance of one lamp divided by the number of lamps. The combined resistance, Fig. 649, equals the sum of the resistances of the two lamps at A multiplied by the resistance of B and divided by the sum of all the resistances. If the resistance of each of the lamps were 110 ohms, the problem would work out thus:

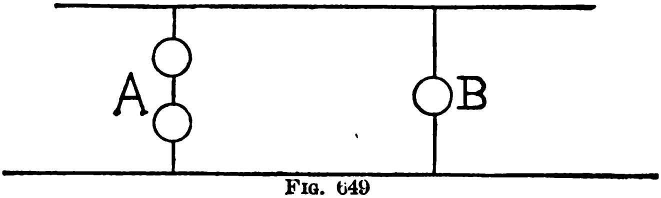


FIG. 649

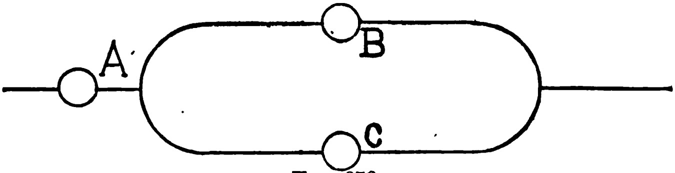


FIG. 650

$$\frac{110+110\times110}{110+110+110}=73\ 1/3.$$

In Fig. 650 the total resistance is

$$\frac{110\times220}{110+220}+110=183\ 1/3.$$

One practical illustration of the above law may be found in the method of switching series arc lamps, Fig. 651. As long as the switch S is open the arc lamp burns, but as soon as the switch is closed the lamp is extinguished because the resistance of the short wire and the switch S is so much less than that of the arc lamp that practically all the current flows through S.

Wiring Systems.—The system of wiring which is most generally used for incandescent lighting and ordinary power purposes is called the two-wire parallel system. In this system of wiring the two wires run side by side, one of them being the positive and one the negative. The lamps, motors and other devices are then connected from one wire to the other. A constant pressure of electricity is maintained between the two wires, and the number and size of lamps, or other apparatus, connected to these two wires, determine how many amperes are required. Each lamp or motor is independent of the others and may be turned on or off without disturbing the others.

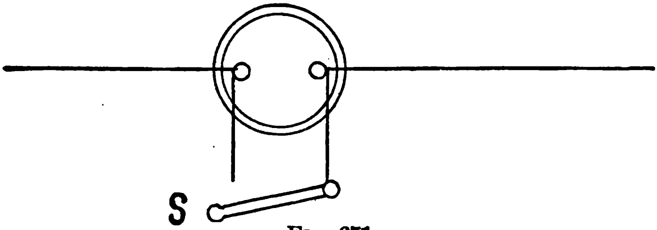


FIG. 651

A diagram of such a system is shown in Fig. 652.

In this system the quantity of current varies in proportion to the number of devices connected to it. Suppose that we are maintaining a pressure or potential or electromotive force of 110 volts on such a system, and that we have connected to the system ten 16 candle power incandescent lamps, consuming one-half ampere each. The total quantity of current to supply these lamps would be 5 amperes. If we should now switch on ten more lamps the quantity of current would be 10 amperes, and the pressure would remain 110 volts. This system is also known as the "constant potential system," or multiple arc system, and among the numerous devices used in connection with it are the constant potential arc lamp, the shunt motor, the compound wound motor, the series motor, incandescent lamps, etc. Electric street railways are also operated on this system. The current supplied through this system of wiring may be either direct or alternating current.

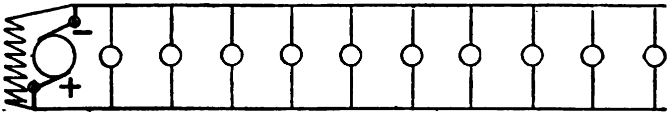


FIG. 652
TWO-WIRE PARALLEL SYSTEM

The series arc system, Fig. 653, is a loop; the greatest electrical pressure being at the terminal, or terminal ends of the loop. The current in such a system of wiring is constant, and the pressure varies as the lamps or other apparatus are inserted in or cut out of the circuit. This system is also called the constant current system. The same current passes through all of the lamps, and the different lamps are also independent of each other.

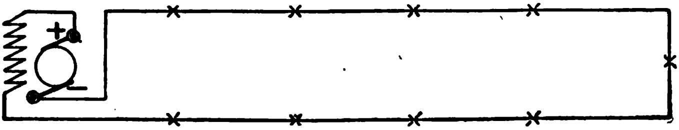


FIG. 653
SERIES ARC SYSTEM

At the present time the series system is used mostly for operating high tension series arc lamps. The use of motors with it has been almost entirely abandoned.

The series multiple system, Fig. 654, is simply a number of multiple systems placed in series. This method of wiring was at one time employed to run incandescent lights from a high tension series arc light circuit, but on account of the danger connected with the use of incandescent lamps, operated from a high tension arc lamp circuit, the system has been abandoned. It is not approved by insurance companies, and consequently is not often used.

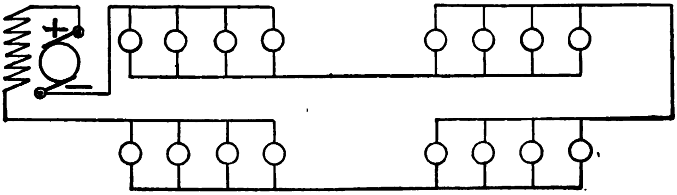


FIG. 654
SERIES MULTIPLE SYSTEM

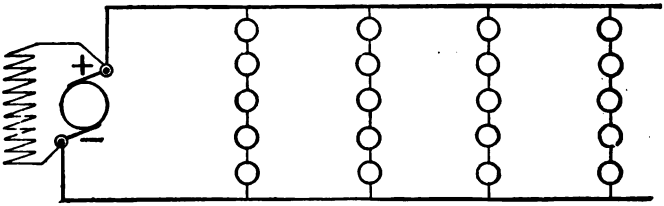


FIG. 655
MULTIPLE SERIES SYSTEM

The multiple series system consists of a number of small series circuits, connected in multiple, as shown in Fig. 655. This system of wiring is used on constant potential systems, where the voltage is much greater than is required by the apparatus to be used, as, for instance, connecting eleven miniature lamps, whose individual pressure required is 10 volts, into a series, and then connecting the extreme ends of such a series to a multiple circuit whose pressure is 110 volts.

The three wire system, Fig. 656, is a system of multiple series. In this system, as its name implies, three wires are used, connected up to the machines in the manner shown in the diagram. Both machines are in series when all lights are turned on, but should all lights on one side of the neutral or center wire be turned off the machine on the other side alone would run the other lights.

One of these wires is positive, the other is negative, and the remaining one or center wire is neutral. In ordinary practice from positive to negative wire, a potential of 220 volts is maintained, while from the neutral wire to either of the outside wires a potential of 110 volts exists. The advantages of such a system are many, principally among them is the use of double the voltage of the two wire system; this reduces the current one-half and allows the use of smaller wires. This system only requires three wires for the same amount of current that would require four in the other system. Motors are supplied at 220 volts, while lights operate at 110. Incandescent lighting circuits can be maintained from either outside wire to the neutral wire. The saving in copper by dispensing with the fourth wire

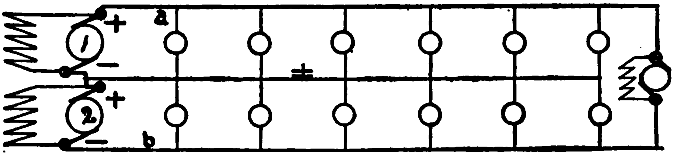


FIG. 656

THREE WIRE SYSTEM

is not the only advantage in the saving of conductors. The neutral wire may be much smaller than the outside wires because it will seldom be called upon to carry much current.

Inside of buildings, however, where overheating of a wire is always dangerous, the neutral wire should be of the same size as the others. By tracing out the circuits in Fig. 656, it will readily be seen that, so long as all lamps are burning, the current passes out of dynamo 1 into the positive wire and from there through the lamps (always two in series) to the negative or — wire, returning over it to the — pole of dynamo 2. So long as an equal number of lamps is burning on each side of the neutral, no current passes over the neutral wire in either direction. But if the positive or + wire should be broken, say at *a*, dynamo 1 will no longer send current and the lamps between the positive and neutral wire will be out.

Dynamo 2 will now supply the lamps between the neutral and the negative wire and for the time being the neutral wire will become positive. Should the negative wire break at *b*, the lamps connected to it would be out and dynamo 1 would supply the lights on its side, the neutral wire becoming negative. When motors of one or more horse-power are used on this system, it is usual to connect them to the outside wires using 220 volts. It is important also to arrange the wiring so that an equal number of lights are installed on each side of the neutral. When the lights and motors are so arranged, the system is said to be "balanced." It is also very important to arrange so that the neutral wire cannot readily be broken. Should the neutral wire be opened while, for instance, fifty lamps were burning on one side and say ten or twenty on the other, the ten or twenty would be broken by the excess voltage. Grounded wires ordinarily cause more trouble than anything else on electric light or power circuits, but with the three wire system, the neutral wire is often grounded. Grounds on this wire are less objectionable than on other wires, because it carries very little current, and that current is constantly varying in direction, so that no great amount of electrolysis can occur at any one place.

Feeders.—(See Fig. 657), as the name implies, is a term used to designate wires which convey the current to any number of other wires, and the feeders become a part of the multiple series, multiple and three wire systems.

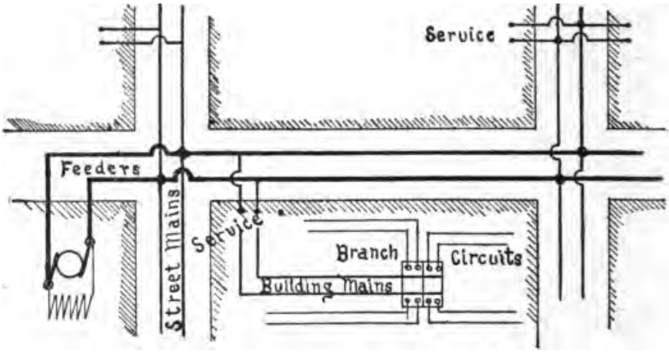


FIG. 657

Distributing mains are the wires from which the wires entering buildings receive their supply.

Service wires are the wires that enter the buildings.

The center of distribution is a term used for that part of the wiring system from which a number of branch circuits are fed by feeder wires. In most buildings the tap lines are all brought to one point, and terminate in cut-out boxes. These cut-out boxes are supplied by the main. Each floor of the building may have a cut-out box, or each floor of the building may have several cut-out boxes of the above description.

Calculation of Wires.—If we desire to transmit or deliver a certain quantity of liquid through a pipe, we estimate the size of the pipe and the comparison of sizes in the pipes by squaring the diameter, in inches, and multiplying the result by the standard fraction .7854. By way of explanation we will dwell upon the above method for a short time. In Fig. 658 we have a surface which measures one inch on all four sides, and which has an area of one square inch.

Now in a circle which is contained in this figure, and which touches all four sides of the square, we would only have .7854 of a square inch. If the diameter of this circle is 2 inches instead of 1, you can readily see by Fig. 659 that its area is four times as great or 2×2=4. We then multiply by the standard number .7854 in order to find the area contained in the two-inch circle; and if the diameter were 3 inches, then 3×3=9, and 9×.7854 would be the area in square inches contained in the three-inch circle.

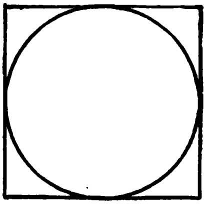


FIG. 658

Again, if we had a square one inch in area, like Fig. 660, and we took one leg of a carpenter's compass and placed it on one corner of this square, striking a quarter-circle from one adjacent corner to the other adjacent corner, the area inscribed by the compass would again be .7854 of a square inch.

The above will explain to the reader the relation between the circular and square mil. The circular mil is a circle one mil ($\frac{1}{1,000}$ of an inch) in diameter. The square mil is a square, one mil long on each side. In the calculation of wires for electrical purposes, the circular mil is generally used, because we need only multiply the diameter of a wire by itself to obtain its area in circular mils. If we used square mils we should have to multiply by .7854.

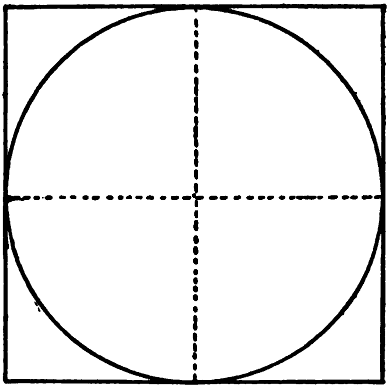


FIG. 659

The resistance of a conductor (wire) increases directly as its length, and decreases directly as its diameter is increased. A wire having a diameter of one mil and being one foot long has a resistance at ordinary temperature of 10.7 to 10.8 ohms. 10.8 ohms is the resistance usually taken. If this wire were two feet long, it would have a resistance of 21.4 ohms, but if it were two mils in diameter and one foot long, it would have a resistance one-fourth of 10.7, or about 2.67.

Every transmission of electrical energy is accompanied by a certain loss. We can never entirely prevent this loss any more than we can entirely avoid friction. But we can reduce our loss to a very small quantity simply by selecting a very large wire to carry the current. This would be the proper thing to do if it were not for the cost of copper, which would make such an installation very expensive. As it is, wires are usually figured at a loss of from 2 to 5 per cent.

The greater the loss of energy we allow in the wires, the smaller will be the cost of wire, since we can use smaller wires with the greater loss.

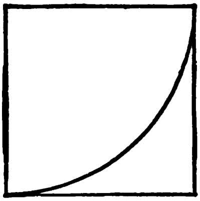


FIG. 660

In long distance transmission and where the quality of light is not very important, a loss of 10 or 20 per cent is sometimes allowed, but in stores, residences, etc., the loss should not exceed 2 or 3 per cent, otherwise the candle power of the lamps will vary too much.

Where the cost of fuel is high the saving in first cost of copper is soon offset by the continuous extra cost of fuel to make up for the losses in the wires.

To determine the size of wire necessary to carry a certain current at a given number of volts loss, we may proceed in the following manner: Multiply the number of feet of wire in the circuit by the constant 10.7, and it will give the circular mils necessary for one ohm of resistance. Multiply this by the amperes, and this will give the circular mils for a loss of one volt. Divide this last result by the volts to be lost, and the answer will be the number of circular mils diameter that a copper wire must have to carry the current with such a loss. After obtaining the number of circular mils required, refer to table 53 and select the wire having such a number of circular mils.

The formula is as follows:

$$\frac{\text{Feet of wire} \times 10.7 \times \text{amperes}}{\text{Volts lost}} = \text{circular mils.}$$

By simply transposing the above terms we obtain another formula, which can be used to determine the volts lost in a given length of wire of a certain size, carrying a certain number of amperes.

The formula is as follows:

$$\frac{\text{Feet of wire} \times 10.7 \times \text{amperes}}{\text{Circular mils}} = \text{Volts lost.}$$

And again, by another change in the terms we obtain a formula which shows the number of amperes that a wire of given size and length will carry at a given number of volts lost:

$$\frac{\text{Circular mils} \times \text{volts lost}}{\text{Feet of wire} \times 10.7} = \text{Amperes.}$$

In computing the necessary size of a service or main wire, to supply current for either lamps or motors, it is necessary to know the exact number of feet from the source of supply to the center of distribution. When the distance of center of distribution is given it is well to ascertain whether it is the true center or not. It may be only the distance from a cut-out box that has been given, when it should have been the distance from the point at which the service enters the building or, perhaps from the point at which the service is connected to the street mains. For when the size is determined it is for a certain loss which is distributed over the entire length of the wire to be installed. The transmission of additional current on the mains in the building increases the drop in volts in the main, and likewise in the service. Most buildings are wired for a certain per cent loss in voltage, estimated from the point where the service enters the building. All additions should be estimated from that point.

In using the formula for finding the proper size wire to carry current, the first thing to be determined is the length of the wire; remember that the two wires are in parallel, and therefore the total length of the wire is twice the total distance from the commencement to the end of the circuit. If the proposed load on this circuit is given in lamps, you may reduce it to amperes, and if the proposed load is given in horse-power, you may reduce it to amperes. The voltage on the circuit is known in either case. You take the loss of the voltage and divide the product of amperes, multiplied by the length, as found, and 10.7 by it; this answer will be the size in circular mils of a wire necessary to carry the amperes.

Example.—What is the size of wire required for a 50-volt system, having 100 lamps at a distance of 100 ft., with a 4 per cent loss?

Answer.—The load of 100 lamps on a 50-volt system is 100 amperes, and a 4 per cent loss of 50 volts is 2 volts. Multiply the total length of the wire, which is twice the distance, or 200 feet, by the 100 amperes of current; this gives us 20,000. Then multiply this by the constant, which is 10.7; this gives us 214,000. Divide this by 2, which is the loss in volts, and you have 107,000 circular mils diameter of wire required.

When determining the size of wire to be used it is always necessary to consult the table of carrying capacities, and this will very often indicate a wire much larger than that determined by the wiring formula, especially if a somewhat high loss is figured on.

When estimating the distance it is not always correct to take the total distance.

To illustrate: Suppose one lamp is 100 feet from the point at which the distance is determined, and the farthest lamp is 400 feet, the remaining lamps being distributed evenly between these two points, we would average the distances between the first and last lamp, which would be 200 feet. It is necessary to use judgment in estimating the mean or average distance, as the lamps or motors are bunched differently in each case.

In a series system the loss in voltage makes considerable difference to the power, but does not affect the quality of the light as much as in a multiple arc or parallel system. In a parallel system the lamps require a uniform pressure, and this can only be had by keeping the loss low. In a series system the lamps depend upon the constant current and the voltage varies with the resistance, in order to keep the current constant. This is accomplished by a regulator on the dynamo, which is designed to compensate for the changes of resistance in the circuit and to increase or decrease the pressure as required.

In estimating the size of wire for a series system you consider the total length of the loop. There is no average distance as the total current travels over the entire circuit. We will assume that you have an arc light circuit of a No. 6 Brown & Sharp gauge wire, and want to find what loss there is in this circuit. You have the area of a No. 6 wire, which is 26,250 circular mils, and the length of the circuit, and from this we will figure the loss in this manner: Assuming the circuit to be 10,000 feet long, and the current 10 amperes, we will multiply 10,000 feet by 10 amperes, and this by 10.7, which gives us 1,070,000, and divide this by 26,250. The answer is 40 volts, lost in the circuit.

Such a circuit would operate at perhaps 2,000 or 3,000 volts, and a loss of 40 volts would not be excessive. It would be wasting a little less energy than is required to burn one large arc lamp.

The *multiple series system* is a number of small wires connected in multiple, and is the same as the multiple are or parallel system. The wire is figured in the same way as for the multiple arc system.

The *series multiple system* is a number of small parallel systems, and these are connected in series by the main wire. The wire is figured the same as for the series system.

The *Edison three-wire system* is a double multiple, and the two outside wires are the ones considered when carrying capacity is figured. When this system is under full load or balanced, the neutral wire does not carry any current, but the blowing of a fuse in one of the outside wires may force the neutral wire to carry as much current as the outside wire and it should, therefore, be of the same size. The amount of copper needed with this system is only three-eighths of that required for a two-wire system.

Wiring Tables.—On the following pages are presented wiring tables 55, 56 and 57 for 110,220 and 500 volt work. These tables are used in the following manner: Suppose we wish to transmit 60 amperes a distance of 1,800 feet at 110 volts and at a loss of 5 per cent. We take the column headed by 60 in the top row and follow it downward until we come to 1,800, or the number nearest to it. From this number we now follow horizontally to the left, and under the column headed by 5 we find the proper size of wire, which is 500,000 c. m. The same current, at a loss of 10, would require only a 0000 wire, as indicated under the column at the left, headed by 10.

Before making selection of wire, always consult table 53 of carrying capacities. This table is taken from the rules of the National Board of Fire Underwriters, and is in general use.

The first three of the following tables are wiring tables for the three standard voltages, 110, 220, 500. From these tables can be found the sizes of wire required to carry various amounts of current (in amperes) different distances (in feet) at several percentages of loss, or the distance the different sizes of wire will carry various amounts of current at several percentages of loss can be found.

These tables are figured on safe carrying capacity for the different sizes of wire. The distances in feet are to the center of distribution.

TABLE 58

CARRYING CAPACITY OF PURE COPPER WIRES.

(Underwriters' Rules.)

B. & S. G.	Table A. Rubber Insulation. Amperes.	Table B. Other Insulations. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

TABLE 54

DIMENSIONS OF PURE COPPER WIRE.

No. B. & S.	Diam. Mils.	Area.		Weight and Length. Sp. Gr. 8.9.		
		Circular Mils.	Square Mils.	Lbs. per 1000 feet.	Lbs. per mile.	Feet per pound.
0000	460.000	211600.0	166190.2	640.73	3383.04	1.56
000	409.640	167805.0	131793.7	508.12	2682.85	1.97
00	364.800	133079.0	104520.0	402.97	2127.66	2.48
0	324.950	105592.5	82932.2	319.74	1688.20	3.13
1	289.300	83694.5	65733.5	253.43	1338.10	3.95
2	257.630	66373.2	52129.4	200.98	1061.17	4.98
3	229.420	52633.5	41338.3	159.38	841.50	6.28
4	204.310	41742.6	32784.5	126.40	667.38	7.91
5	181.940	33102.2	25998.4	100.23	529.23	9.98
6	162.020	26250.5	20617.1	79.49	419.69	12.58
7	144.280	20816.7	16349.4	63.03	332.82	15.86
8	128.490	16509.7	12966.7	49.99	263.96	20.00
9	114.430	13094.2	10284.2	39.65	209.35	25.22
10	101.890	10381.6	8153.67	31.44	165.98	31.81
11	90.742	8234.11	6467.06	24.93	137.65	40.11
12	80.808	6529.94	5128.60	19.77	104.40	50.58
13	71.961	5178.39	4067.07	15.68	82.792	63.78
14	64.084	4106.76	3225.44	12.44	65.658	80.42
15	57.068	3256.76	2557.85	9.86	52.069	101.40
16	50.820	2582.67	2028.43	7.82	41.292	127.87
17	45.257	2048.20	1608.65	6.20	32.746	161.24
18	40.303	1624.33	1275.75	4.92	25.970	203.31
19	35.890	1288.09	1011.66	3.90	20.594	256.39
20	31.961	1021.44	802.24	3.09	16.331	323.32
21	28.462	810.09	636.24	2.45	12.952	407.67
22	25.347	642.47	504.60	1.95	10.272	514.03
23	22.571	509.45	400.12	1.54	8.1450	648.25
24	20.100	404.01	317.31	1.22	6.4593	817.43
25	17.900	320.41	251.65	.97	5.1227	1030.71
26	15.940	254.08	199.56	.77	4.0623	1299.77
27	14.195	201.50	158.26	.61	3.2215	1638.97
28	12.641	159.80	125.50	.48	2.5548	2066.71
29	11.257	126.72	99.526	.38	2.0260	2606.13
30	10.025	100.50	78.933	.30	1.6068	3286.04
31	8,928	79.71	62.603	.24	1.2744	4143.18
32	7.950	63.20	49.639	.19	1.0105	5225.26
33	7.080	50.13	39.360	.15	.8015	6588.33
34	6.304	39.74	31.212	.12	.6354	8310.17
35	5.614	31.52	24.753	.10	.5039	10478.46
36	5.000	25.00	19.635	.08	.3997	13209.98
37	4.453	19.83	15.574	.06	.3170	16654.70
38	3.965	15.72	12.347	.05	.2513	21006.60
39	3.531	12.47	9.7923	.04	.1993	26487.84
40	3.144	9.88	7.7635	.03	.1580	33410.05

1 mile pure copper wire $\frac{1}{16}$ in. diam.=13.59 ohmns at 15.5° C. or 59.9° F.
1 circular mil. is .7854 square mil.

TABLE 55 WIRING TABLE FOR 110 VOLTS.

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the Number of Amperes; Those Below the Distance in Feet.																		
2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	125	150	200	250	300	350
......	......	......	......	......	500000	127315	63657	42438	25463	16975	12731	10185	8487	6365	5092	4243	3182	2546	2037	1697	1273	1018	849	727
......	......	......	......	500000	400000	101850	50925	33950	20370	13580	10185	8148	6790	5092	4074	3395	2546	2037	1629	1358	1018	815	679	...
......	......	......	500000	400000	300000	76380	38190	25460	15276	10184	7638	6111	5092	3819	3055	2546	1910	1527	1222	1018	763	611	...	...
......	......	500000	400000	300000	0000	53880	26940	17960	10776	7184	5388	4311	3592	2694	2155	1796	1347	1077	862	718	538	....	...	...
......	......	400000	300000	0000	000	40410	20205	13470	8082	5488	4041	3233	2744	2020	1616	1372	1010	808	647	538	....	....	...	...
......	500000	300000	0000	000	00	33885	16942	11295	6777	4517	3388	2711	2258	1694	1355	1129	822	677	542	452	....	....	...	...
......	400000	0000	000	00	0	26880	13440	8960	5377	3584	2688	2151	1792	1344	1075	896	672	537	430	....	....	....	...	...
500000	300000	000	00	0	1	21310	10655	7103	4262	2841	2131	1705	1420	1065	852	710	532	426	341	....	....	....	...	...
400000	0000	00	0	1	2	16900	8450	5633	3380	2253	1690	1352	1126	845	676	563	422	338	....	....	....	....	...	...
300000	000	0	1	2	3	13400	6700	4466	2680	1786	1340	1072	893	670	536	447	335	....	....	....	....	....	...	...
0000	00	1	2	3	4	10605	5302	3535	2121	1413	1060	848	706	530	424	353	....	....	....	....	....	....	...	...
000	0	2	3	4	5	8430	4215	2810	1686	1124	843	675	562	422	337	281	....	....	....	....	....	....	...	...
00	1	3	4	5	6	6685	3342	2228	1337	890	668	535	445	334	267	....	....	....	....	....	....	....	...	...
0	2	4	5	6	7	5300	2650	1766	1060	706	530	424	353	265	212	....	....	....	....	....	....	....	...	...
1	3	5	6	7	8	4220	2110	1406	844	562	422	338	281	211	....	....	....	....	....	....	....	....	...	...
2	4	6	7	8	9	3330	1665	1110	666	444	333	266	222	....	....	....	....	....	....	....	....	....	...	...
3	5	7	8	9	10	2640	1320	880	528	352	264	211	....	....	....	....	....	....	....	....	....	....	...	...
4	6	8	9	10	11	2095	1047	698	419	278	209	.....	....	....	....	....	....	....	....	....	....	....	...	...
5	7	9	10	11	12	1660	830	553	333	221	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
6	8	10	11	12	13	1320	660	440	264	176	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
7	9	11	12	13	14	1045	522	348	209	.....	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
8	10	12	13	14	15	830	415	276	166	.....	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
9	11	13	14	15	16	655	327	218	.....	.....	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
10	12	14	15	16	......	525	263	175	.....	.....	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
11	13	15	16	......	......	412	206	137	.....	.....	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
12	14	16	......	......	......	330	165	111	.....	.....	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
13	15	......	......	......	......	263	131	87	.....	.....	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
14	16	......	......	......	......	206	103	68	.....	.....	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
15	......	......	......	......	......	165	82	55	.....	.....	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...
16	......	......	......	......	......	131	65	43	.....	.....	.....	.....	....	....	....	....	....	....	....	....	....	....	...	...

One 16-Candlepower 55 Watt Incandescent Lamp=½ ampere. One Horsepower=6.78 amperes.
One 2000-Candlepower Constant Potential Arc Lamp=5 amperes.

TABLE 56 WIRING TABLE FOR 220 VOLTS

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the number of Amperes; Those Below the Distance in Feet.																		
2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	120	160	200	250	300	350
......	......	......	......	......	500000	254630	127315	84877	50926	33950	25463	20370	16975	12731	10185	8487	6366	5092	4243	3183	2546	2037	1697	1455
......	......	......	......	500000	400000	203700	101850	67900	40740	27160	20370	16295	13580	10185	8147	6790	5092	4073	3395	2546	2036	1629	1357	......
......	......	......	500000	400000	300000	152775	76387	50924	30550	20370	15275	12222	10183	7637	6111	5091	3819	3055	2546	1910	1528	1222	......	......
......	......	500000	400000	300000	0000	107780	53890	35926	21556	14370	10778	8622	7185	5389	4311	3592	2695	2155	1796	1348	1077	......	......	......
......	......	400000	300000	0000	000	85450	42725	28483	17090	11393	8545	6836	5696	4272	3418	2848	2136	1709	1424	1068	......	......	......	......
......	500000	300000	0000	000	00	67745	33872	22581	13549	9032	6774	5420	4516	3387	2710	2258	1679	1355	1129	839	......	......	......	......
......	400000	0000	000	00	0	53770	26885	17923	10754	7170	5377	4302	3585	2688	2151	1792	1344	1075	896	......	......	......	......	......
500000	300000	000	00	0	1	42620	21310	14206	8524	5682	4262	3410	2841	2131	1705	1420	1065	852	710	......	......	......	......	......
400000	0000	00	0	1	2	34055	17027	11351	6811	4540	3405	2724	2270	1702	1362	1135	851	681	......	......	......	......	......	......
300000	000	0	1	2	3	26570	13285	8856	5314	3542	2637	2125	1771	1328	1062	885	664	......	......	......	......	......	......	......
0000	00	1	2	3	4	21255	10627	7085	4251	2834	2125	1700	1417	1062	850	708	......	......	......	......	......	......	......	......
000	0	2	3	4	5	16855	8427	5618	3371	2247	1685	1348	1123	842	614	562	......	......	......	......	......	......	......	......
00	1	3	4	5	6	13365	6682	4455	2673	1782	1336	1050	891	668	525	......	......	......	......	......	......	......	......	......
0	2	4	5	6	7	10560	5280	3520	2112	1413	1060	848	706	530	424	......	......	......	......	......	......	......	......	......
1	3	5	6	7	8	8405	4202	2801	1681	1120	840	672	560	420	......	......	......	......	......	......	......	......	......	......
2	4	6	7	8	9	6665	3332	2221	1333	888	666	533	444	......	......	......	......	......	......	......	......	......	......	......
3	5	7	8	9	10	5275	2637	1758	1055	703	527	422	......	......	......	......	......	......	......	......	......	......	......	......
4	6	8	9	10	11	4190	2095	1396	838	558	419	......	......	......	......	......	......	......	......	......	......	......	......	......
5	7	9	10	11	12	3325	1662	1108	665	443	......	......	......	......	......	......	......	......	......	......	......	......	......	......
6	8	10	11	12	13	2635	1317	878	527	351	......	......	......	......	......	......	......	......	......	......	......	......	......	......
7	9	11	12	13	14	2090	1045	696	418	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
8	10	12	13	14	15	1655	827	551	331	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
9	11	13	14	15	16	1315	657	438	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
10	12	14	15	16	......	1050	525	350	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
11	13	15	16	......	......	828	414	276	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
12	14	16	......	......	......	657	328	219	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
13	15	......	......	......	......	526	263	175	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
14	16	......	......	......	......	414	207	138	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
15	......	......	......	......	......	329	164	109	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
16	......	......	......	......	......	265	132	88	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

One 16-Candlepower 55 Watt Incandescent Lamp=¼ ampere. One Horsepower=3.39 amperes.
One 2000-Candlepower Constant Potential Arc Lamp=2½ amperes.

TABLE 57 WIRING TABLE FOR 500 VOLTS.

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the Number of Amperes; Those Below the Distance in Feet.																
2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	120	150	170	200
......	......	......	......	......	500000	578700	289350	192900	115740	77160	57870	46296	38580	28935	23148	19290	14467	11574	9645	7716	6800	5787
......	......	......	......	500000	400000	460645	230322	153550	92129	61420	46064	36852	30710	23032	18426	15355	11516	9213	7677	6142	5420	4606
......	......	......	500000	400000	300000	347220	173610	115740	69444	45296	34722	27777	22648	17361	13888	11324	8680	6944	5662	4629	4085	3472
......	......	500000	400000	300000	0000	244950	122475	81650	48990	32660	24495	19595	16330	12247	9797	8165	6123	4898	4082	3266	2882	2449
......	......	400000	300000	0000	000	194215	97107	64738	38843	25895	19421	15537	12947	9710	7768	6473	4855	3884	3236	2589	2285	.....
......	500000	300000	0000	000	00	154025	77012	51341	30805	20536	15402	12322	10268	7701	6161	5134	3850	3080	2567	2054	.....	.....
......	400000	0000	000	00	0	122210	61105	40736	24442	16293	12221	9775	8146	6110	4887	4073	3055	2443	2036	.....	.....	.....
500000	300000	000	00	0	1	96405	48202	32135	19281	12854	9640	7712	6427	4820	3856	3213	2410	1928	1606	.....	.....	.....
400000	0000	00	0	1	2	76565	38282	25521	15313	10208	7656	6125	5104	3828	3062	2552	1914	1531	.....	.....	.....	.....
300000	000	0	1	2	3	60915	30457	20305	12183	8122	6091	4873	4061	3045	2436	2030	1522	.....	.....	.....	.....	.....
0000	00	1	2	3	4	48310	24155	16103	9662	6441	4831	3864	3220	2415	1932	1610	.....	.....	.....	.....	.....	.....
000	0	2	3	4	5	38282	19140	12760	7656	5104	3828	3062	2552	1914	1531	1276	.....	.....	.....	.....	.....	.....
00	1	3	4	5	6	30457	15228	10152	6091	4061	3045	2436	2030	1522	1218	.....	.....	.....	.....	.....	.....	.....
0	2	4	5	6	7	24155	12077	8051	4831	3220	2415	1932	1610	1207	966	.....	.....	.....	.....	.....	.....	.....
1	3	5	6	7	8	19140	9570	6380	3828	2552	1914	1531	1276	957	.....	.....	.....	.....	.....	.....	.....	.....
2	4	6	7	8	9	15229	7614	5076	3045	2030	1522	1218	1015	.....	.....	.....	.....	.....	.....	.....	.....	.....
3	5	7	8	9	10	12077	6039	4026	2415	1610	1207	978	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4	6	8	9	10	11	9570	4785	3190	1914	1276	957	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	7	9	10	11	12	7639	3819	2546	1527	1018	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	8	10	11	12	13	6039	3019	2013	1207	805	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7	9	11	12	13	14	4785	2392	1595	957	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	10	12	13	14	15	3819	1910	1273	763	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
9	11	13	14	15	16	3019	1510	1005	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	12	14	15	16	......	2392	1195	797	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
11	13	15	16	......	......	1910	950	636	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
12	14	16	......	......	......	1510	755	503	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
13	15	......	......	......	......	1195	597	398	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
14	16	......	......	......	......	950	475	316	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15	......	......	......	......	......	755	377	252	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
16	......	......	......	......	......	597	298	199	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

One Horsepower=1.49 amperes. When lights are used the lamps are put in series.

TABLE 58

SIZES, WEIGHTS, AND RESISTANCE OF PURE COPPER WIRE.

Size B. & S. Gauge.	Diam. Mils.	Area		Weather-Proof Wire						Bare Wire			Resistance at 75° F.			
				Double Braided			Triple Braided									
		Circular Mils.	Square Mils.	Pounds per 1000 feet.	Pounds per mile.	Feet per pound	Pounds per 1000 feet.	Pounds per mile.	Feet per pound.	Pounds per 1000 feet.	Pounds per mile.	Feet per pound.	R. Ohms per 1000 feet.	Ohms per mile.	Feet per ohm.	Ohms per pound.
....	707 160	500000.0	392700	1680	8870	.59	1744	9208	.57	1562	8247	.64	.02079	.10978	48290	.00001322
....	632 455	400000.0	314160	1343	7091	.74	1405	7418	.76	1209	6489	.81	.02589	.13723	38630	.00002063
....	547 722	300000.0	235620	1055	5570	.94	1112	5873	.90	941	4968	1.06	.03465	.18297	28980	.00003656
0000	460 000	211600.0	166190	700	3718	1.42	746	3940	1.34	639.33	3375.7	1.56	.04904	.25891	20392.9	.00007653
000	409 640	167805.0	131790	565	2983	1.77	599	3161	1.67	507.01	2677.0	1.97	.06181	.32649	16172.1	.00012169
00	364 800	133079.0	104520	460	2433	2.17	493	2600	2.03	402.09	2123.0	2.49	.07797	.41168	12825.4	.00019438
0	324 950	105592.5	82887	371	1963	2.69	397	2095	2.52	319.04	1684.6	3.14	.09827	.51885	10176.4	.00030734
1	289 300	83694.5	65733	281	1483	3.56	299	1572	3.35	252.88	1335.2	3.95	.12398	.65460	8066.0	.00048920
2	257 630	66373.2	52130	231	1219	4.33	248	1310	4.03	200.54	1058.8	4.99	.15633	.82543	6396.7	.00077784
3	229 420	52633.5	41339	193	1018	5.18	207	1091	4.84	159.03	839.68	6.29	.19714	1.04090	5072.5	.0012370
4	204 310	41742.6	32784	152	802	6.58	162	855	6.17	126.12	665.91	7.93	.24858	1.31248	4022.9	.0019666
5	181 940	33102.2	25998	123	650	8.12	134	710	7.45	100.01	528.05	10.00	.31346	1.65507	3190.2	.0031273
6	162 020	26250.5	20617	104	550	9.60	112	595	8.87	79.32	418.81	12.61	.39528	2.08706	2529.9	.0049723
7	144 280	20816.7	16349	.....	.....	......	.....	.....	.....	62.90	332.11	15.90	.49845	2.63184	2006.2	.0079078
8	128 490	16509.7	12966	66	352	15.00	74	387	13.65	49.88	263.37	20.05	.62849	3.31843	1591.1	.0125719
9	114 430	13094.2	10284	.....	.....	......	.....	.....	.....	39.56	203.88	25.28	.79242	4.18400	1262.0	.0199853
10	101 890	10381.6	8153.2	48	250	21.11	52	271	19.50	31.37	165.63	31.38	.99948	5.27726	1000.5	.0317946
11	90 742	8231.11	6467.0	.....	.....	......	.....	.....	.....	24.88	137.37	40.20	1.2692	6.65357	793.56	.0505413
12	80 808	6529.94	5128.6	31	160	33.00	33	172	30.36	19.73	104.18	50.69	1.5890	8.39001	629.82	.0803641
13	71 961	5178.39	4067.1	.....	.....	......	.....	.....	.....	15.65	82.632	63.91	2.0047	10.5798	499.06	.127788
14	64 084	4106.76	3225.4	23	118	44.74	24	125	42.24	12.41	65.525	80.38	2.5266	13.3405	395.79	.203180
15	57 068	3256.76	2557.8	.....	.....	......	.....	.....	.....	9.84	51.956	101.63	3.1860	16.8223	313.87	.323079
16	50 820	2582.67	2028.6	14	76	69.47	15	80	66.00	7.81	41.237	128.14	4.0176	21.2130	248.90	.513737

Correcting Dynamo Troubles.—Inasmuch as the use of small direct current electric dynamos is becoming very general, and since they are frequently in operation under the supervision of users who are not as a rule familiar with electrical machinery, a few simple pointers relative to the care and maintenance of an electric dynamo may help some user to avoid considerable annoyance.

Electrical machinery, even though it has been largely shrouded in mystery, is, nevertheless, comparatively simple apparatus in its operation and maintenance. To a considerable degree it is a delicate piece of mechanism, by which is meant that it cannot be handled with the same treatment as one would expect to give a clumsy, crude, or inexpensive device. However, there are a few underlying principles which govern such dynamos as are ordinarily used in small isolated plants, which, if they are observed, will enable practically any operator to maintain and keep in perfect running condition any well constructed machine. When the dynamo is received from the factory it should be carefully examined to see if it is in apparently good condition, or whether it shows evidence of having been injured by rough handling in transit. If this inspection points to its having arrived in good condition, its installation should be considered in a general way along the lines similar to those which would be observed for the installation of any piece of machinery. Care should be taken to see that the bearings are properly supplied with oil; that the dynamo stands perfectly level on its foundation; that the belt is of good quality and free from bumps or improper lacing. It may be noted that the dynamo does not necessarily require an independent foundation, which is demanded by some classes of apparatus. Because of the fact that its vibration is very slight, any rigid or substantial floor will answer for this purpose.

In starting up a dynamo, only two things which might be termed "electrical" need be specially considered. The first is the direction of rotation, because each dynamo as shipped from the factory is so connected as to run in only one direction and will not generate current if the direction of rotation is reversed. It is an easy matter to change the connections on a machine so that a reversed direction is possible, and a sheet of instructions furnished with the dynamo usually covers instructions for this modification, but it should be remembered that each dynamo as received by the user is so connected as to operate in only one direction.

The second matter for consideration is the speed of the dynamo, which should not be less than the speed given on the name plate nor greater than ten per cent above the speed. A slower speed would interfere with the building up of the voltage, while a higher speed would deliver an excessive current from the machine. It is needless to add that the directions for wiring connections furnished with the dynamo should be followed carefully.

If, after a dynamo has once been running satisfactorily, there occurs some difficulty in its operation, the probabilty is that, unless the occasion of the trouble is due to some mechanical injury or to the dynamo having become saturated with water or oil, the nature of the trouble will most frequently manifest itself in one or two ways. The first is that the dynamo will refuse to generate current, and the second is that sparking will show itself between the commutator and the brushes. Under this latter head it is worth remembering that the heating of a dynamo is generally due to some cause which, if it existed to a greater degree, would manifest itself in sparking, so that many times the heating of the machine means that trouble exists to a limited extent, which, if it occurred in a greater degree, would manifest itself in sparking. A common exception, however, to this statement is that the brushes, if pressing too firmly on the commutator, will from their friction produce heat. With the above explanation, the more frequent difficulties can be classified under the two heads, "Failure of the dynamo to generate" and "Sparking at the commutator."

If, on starting a dynamo, after its use has been discontinued for a time, it refuses to generate, which means that the operator is unable to secure electricity from it, he should first assure himself that the machine is operating at its proper speed and that there has been no speed reduction, due either to a slowing up of the motive power or to a slippage of the belt. If no such difficulty appears, the next investigation should determine as to whether or not the resistance of the rheostat remains in the field circuit. In many instances dynamos can frequently be made to generate by simply moving the handle of the rheostat to the point marked "highest voltage." The third and possibly most common cause of failure of a dynamo to generate is due to a defective contact between the commutator and the brushes. This may be caused by a lack of proper tension on the brushes, due either to their being too weak or their need of readjustment. Again the brushes and holders may have become dirty and gummy, preventing their proper action. An excessive amount of grease or dirt on the commutator occasionally (especially in cold weather) forms a scum over its surface which intervenes between it and the brushes, retarding the flow of the current. It is possible that the obstacle in the path of the current may lie else-where than between the brushes and the commutator; as, for instance, loose connection may exist in the wire leading from the brushes to the head post. However, the operator can look intelligently for the trouble when he realizes that the early current generated when the dynamo begins to operate is of slight intensity, and obstacles which would not interfere with the flow of the current of ordinary proportions will retard the flow of this initial current, consequently a very slight resistance or hindrance may prevent the dynamo from generating.

To these statements may be added the facts that the brushes may have become moved from their proper position or the dynamo may have lost its magnetism. The latter condition, however, is rare; and the former will not exist unless the machine has been tampered with. In a later paragraph is given information relative to the adjustment of the brushes.

This brings us up to the general manifestation of trouble, namely, sparking at the commutator, which is probably the most frequent difficulty encountered in a dynamo. A small red spark, which can be easily recognized as occasioned by dirt, is not seriously injurious, and a cleaning of the commutator and brushes will overcome it. However, a vicious, spitting spark will, in the course of a comparatively brief time, materially injure the dynamo, and when first detected, steps should be taken to overcome it without delay.

Briefly indicating the causes of sparking which do not permit of ready classification, it may be possibly occasioned by an excessive overload on the machine, due to a leakage in the wiring or to the use of too many lights. If this is responsible for the sparking, the machine will heat materially in all its parts. It may be true that an open circuit or a break in the wiring of the armature may exist. In this instance the spark will be very vicious, and an examination of the commutator will show that it has been burned on one of the mica lines across its surface. An open circuit in one of the fields may also result in sparking, but this can be determined by an unequal heating of the fields.

Coming, however, to the two most common causes of sparking: the first lies in the fact that the contact between the commutator and the brushes may not be firm and uniform. The commutator itself may be rough, or the bearing surface of the brushes may be irregular; roughness of the commutator resulting occasionally by its having been burned down or worn. Occasionally the copper wears more rapidly than the mica, leaving the mica projecting upon the surface of the commutator. If the commutator is rough, a piece of No. 2 sandpaper held firmly on its surface while it is in operation will overcome minor irregularities. If this does not correct the trouble, the armature should be taken to a first-class machine shop and the commutator turned off in a lathe.

If the brushes are so worn that they do not fit snugly on the commutator, fasten a strip of No. 2 sandpaper around the face of the commutator, the sand side out; then revolve the commutator with this strip of sandpaper attached to it until the bearing surface of the brushes will be trued up, insuring a perfect contact. Strange as it may seem, the most common cause of sparking, occasioned by an improper contact, lies in the fact that the user does not recognize that carbon brushes wear out and occasionally need to be replaced. Frequently machines are sent back to the manufacturer for repairs when the only occasion of the trouble is that the carbon brushes have been worn until they cannot rest firmly on the commutator. When the brushes become so worn that it is difficult with the mechanism of the holder to secure a firm pressure against the commutator, they should be renewed with new and longer brushes.

The last occasion for sparking which will be mentioned is that the brushes may have been shifted out of their proper position in reference to each other and to the commutator. On machines which have two-field coils the brushes should rest on the commutator at points which are exactly opposite to each other. On machines which have four-field coils these points should be exactly 90° apart. If the brushes are properly spaced in reference to each other, then their correct position on the commutator becomes a matter of locating what is known as the "neutral point." In order to locate this neutral point, move the rocker arm which carries all the brushes around with the direction of rotation, while the machine is in operation, and carrying a comparatively light load. Do this until a slight spark appears, then move the rocker arm back in the opposite direction just enough to stop the sparking; this will be the neutral point.

PRACTICAL POINTS.

Brushes and Commutators.—Brush holders and commutators will sometimes show excessive temperatures because of the heat which may come from a bearing in which the armature shaft revolves. The failure of a bearing upon a dynamo or a motor to run cool may be due to any one of a great variety of causes, some of which are mechanical and others electrical.

A common cause, and one which is not infrequently overlooked is that of lack of sufficient oil in the bearing for the purposes of lubrication. When renewing the supply of oil to a bearing care should be exercised in the choice of oil, making certain that it is free from dirt or grit, and that it is an oil of good quality for the purpose in hand. The passages or oil ducts should be carefully examined and kept perfectly clear for the free running of the lubricant. A bearing may be leaking at some point, causing the oil to run off much sooner than an attendant would think, and this kind of a defect should be carefully guarded against.

The modern dynamos and motors have their bearings so designed that they are self-oiling, *i. e.,* the oil is carried by means of chains or rings from the oil chamber beneath the bearing proper, up and over the shaft and through grooves provided for the purpose, returning to the well to be used over and over again. Gauge glasses are nearly always provided by means of which it is possible to observe at any and all times the quantity of oil remaining in the well. Oil used over and over again in this manner is quite likely to gather foreign impurities. It is good practice to remove the oil from bearings at least once a month, clean out the bearing thoroughly with gasoline, filter carefully the oil that is left and return the same to the bearing, adding a sufficient quantity of fresh oil to make up for any loss which has been the result of operation.

Gritty substances are very likely to work into bearings at different times, depending upon the use which is made of a motor or a generator. If electrical apparatus is to be placed in a space that is dirty, and cannot well be kept clean, then it is a good precaution to have the machine suitably enclosed, or else to have the bearings completely enclosed with tight-fitting plates about the shaft so as to exclude foreign substances. Whenever it is found necessary to wash out a bearing in order to remove any dirt, care should be exercised not to get any water or kerosene upon the commutator or windings of the machine.

A roughened shaft or a tight fit between the shaft and the sleeve of the bearing may cause heating. These difficulties are purely mechanical and are easily remedied, once that the source of the trouble is ascertained.

Sudden and excessive strains sometimes spring the shaft of a generator or a motor, and it not infrequently happens that with some types of bearings they are thrown out of line. Either of these causes will bring about a heating of the bearing. A bent or crooked shaft can rarely ever be straightened, the only remedy being a new one. Bearings that can be thrown out of line for the reasons mentioned are also susceptible of being properly aligned by means of the caps and screws for holding them in position.

The end thrust of a collar on the armature shaft, upon one side or the other of the machine, may cause a heated bearing. When machines are driven by belting, or when motors are connected with shafting by belting, it is an easy matter to ascertain whether the armature is running freely with respect to the belt connection. A stick placed against the end of the shaft would enable one to move the armature back and forth with very little effort. In fact, every armature should have free end play, and if a test with a stick as mentioned does not show that such a free end play does exist, then the machine should be lined up with respect to its belt, so that such end play is secured.

The bearings may wear down sufficiently in time to permit of the armature bands rubbing against the pole pieces, or stationary iron of the machine. This can often be detected by placing the ear near the frame of the machine opposite the pole piece where it is thought that the armature might come in contact. It might also be detected by turning the armature over slowly with the belt removed and with the field current turned on. It might also happen, however, that the armature will not touch any of the field poles, except when running under load with the belt on. The positive evidence of rubbing lies in an examination of the circumference of the armature itself when the bands around the armature will show whether there has been any rubbing or not. This kind of an examination can usually be made without removing the armature from the machine. If there should be positive evidences of rubbing, it must not be allowed to continue.

The pulley, the belt or other parts of the revolving armature shaft may rub against adjacent surfaces, and bring about a scraping or a rattling noise. The movement of the shaft back and forth in its bearings in one direction or another may stop the noise, in which case it will be a simple matter to locate the cause, after which it will be an equally simple matter to remedy the trouble.

Generally, in starting up a new generator or motor, the new and unused carbon brushes upon a new, and previously unused commutator will cause an unpleasant squeaking or a hissing. The sound is usually of a high pitch and is easily located. Sometimes, it may be due to but one or two new brushes. These can be located by removing one brush at a time until the noisy ones are found. Then by moistening them slightly with a light oil, the noise from that particular brush will be stopped. There should not, however, be so much oil used for this purpose so that any of it will adhere to the brush in the form of drops. It sometimes happens that the commutator has not been finished off as smoothly as it should have been and this, of course, would cause a considerable humming until the commutator surface had been worn over sufficiently to take on a polished appearance. If the commutator is rough enough to cause a hissing of the brushes, it should be polished off by hand before it is put into operation. This can be done in the manner already described, and would insure a much better commutator in service than if allowed to run along in the rough state, trusting to luck that it will assume a polished appearance as a result of operating conditions alone.

A squeak due to the slipping of a belt upon the pulley is easily located, and not confounded with any other noise which may result from operating any class of machinery. Whenever such slipping of a belt occurs, it means a loss of power, and that means expensive operation. A care for the details of operating costs will not permit of a squeaking belt at any point.

Another kind of humming is often present in motors and in some kinds of generators. This is the humming which is something of a musical sound, and is likely to be confined to the armature teeth as they pass the pole faces at high speed. It is a molecular vibration due to the magnetic reversals in the iron. If it is an objectionable feature in the operation, it may be remedied by trimming off the ends of the pole faces so that the full length of an armature tooth would not be likely to leave the pole face throughout its entire length at the same instant of time, but would shade off instead. The testing of generators and motors in the shops of the builders, however, is supposed to reveal excessive humming, and the trimming of pole faces should be done before the machine is sent to the shipping room. In general, it is always well to be certain that the noises of operation come from the electrical apparatus, and not from some other equipment which might be close by.

Transformer Oil.—Transformer oil, its proper character, treatment and use, has been much neglected by central station engineers. It forms one of the weak links in the chain of a high-tension electric-transmission system. In its dual function as insulator and cooler, it requires high dielectric strength, and high flash point, combined with great fluidity. It should be neutral so as to not dissolve the insulation of the core and coils immersed in it.

Of these qualities, the dielectric strength is the most variable, for it depends largely upon the amount of moisture present. The popular axiom that oil and water do not mix is not scientifically correct, for oil does absorb a small amount of moisture that materially lessens its dielectric strength. Instances have been known of transformer oil having broken down under 16,000 volts when wet, but which stood the test of 40,000 volts after being dried.

While oil and water do not chemically mix, they may mingle so closely as to require steam, or rheostat heating to remove the water. Every precaution should be taken to keep oil dry during shipment and in use, for it abhors dehydration even more than nature abhors a vacuum.

It should have a high fire or flash test to eliminate danger of fire. Crude oil is refined by frictional distillation, the most volatile products passing off first. These are low in gravity and in burning temperature, as is exemplified by gasoline. Kerosene for use in lamps is one of the next products, soon followed by an oil suitable for transformer purposes. This usually has a gravity of 30° Baume or less, and burns at about 300° Fahrenheit. The higher the temperature at which the product is distilled, the greater is its viscosity. Consequently, what is gained in flashing temperature is lost in fluidity. Acid introduced into the refining must be removed by adding just enough alkali to render the oil neutral. Disastrous fires have been known to result from the volatilization of the oil by an arc.

Another frequent trouble is the deposition of a thick, carbonaceous, jelly-like sludge on the cooling coils, and in the circulating ducts. The former are covered so thick that cooling is not effected, and the latter are so clogged that circulation is difficult. Such deterioration generally occurs when the oil has been overheated. The deposit is easily washed off when hot, but becomes hard and brittle upon exposure to the air, resembling bitumen in this respect. The deposits around the points of high potential allow creepage, so that a medium of high resistance may become a conductor.

But careful examinations of these troubles show that they are usually due to no inherent fault of the oil, but to the transformer design, or more particularly to the attendant's carelessness.

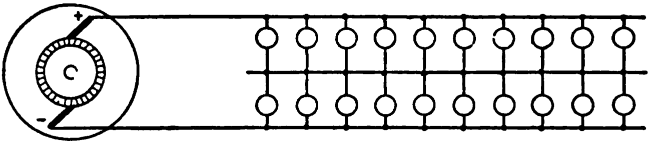


Fig. 661

Careful breakdown tests should be made not only when the oil is furnished, but at frequent intervals thereafter, once a month not being too often for main stations. Tests for acidity will avoid the destruction of the insulation by dissolving, and flash tests will often prevent fires. The carbon may be removed by occasional filtering. In case of leaky cooling coils, the water should be drawn off from the bottom until such time as the transformer can be taken out of service and properly repaired.

All this trouble occurs with both water, and self-cooling transformers. Where water is plentiful, it has been suggested that outside circulation of the oil would cause better cooling, and larger ventilating ducts would not become clogged. We attain success only by the most careful attention to the details of our work. Look after the oil, and transformer troubles will take care of themselves.

Three Wire System with One Dynamo.—When the load on one side of the middle or neutral wire exactly equals the load on the other side, as in Fig. 661, the circuit is balanced, but it is very seldom that such load conditions exist, at least for any length of time, and when there is a difference between the loads carried by the two sides, the circuit is unbalanced.

In order therefore to successfully operate a three wire system with one dynamo, it becomes necessary to provide some method of taking care of the surplus current on the lightly loaded side, and transferring it to the heavily loaded side; in other words, to balance the circuit. There are two methods by which this may be accomplished.

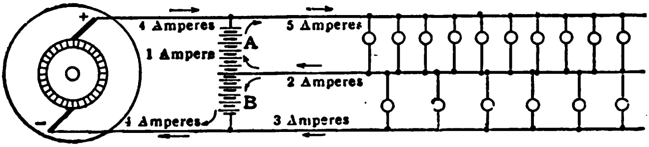


FIG. 662

The first and most simple method of compensating for unbalancing is to connect a storage battery between the two main wires, and then connect the neutral wire to the middle point of the battery, as shown in Fig. 662. Here are shown connected 10 lamps on one side, and 6 on the other. The direction of flow of the current is indicated by the arrows. Assuming that the resistance of each lamp is 220 ohms, which is the ordinary value for 110 volt lamps, the joint resistance of the group of 10 lamps would be

$220 \div 10 = 22$ ohms. The joint resistance of the 6 lamps on the other side would be $220 \div 6 = 36.66$ ohms.

The total resistance of both groups of lamps would be $22 + 36.66 = 58.66$ ohms, and the volume of current flowing through both groups would be $220 \div 58.66 = 3.75$ amperes. Assuming that each lamp requires ½ ampere of current, the group of 10 will require 5 amperes, and the group of 6 requires 3 amperes. As the volume of current equals 3.75 amperes, it is evident that the 10 lamps will not get enough current, while the group of 6 will get too much, unless, as before mentioned, a balancer be provided, and right here is where the storage battery enacts its role. Under the conditions shown in Fig. 662, the A half of the battery will deliver just enough current, provided the voltages are suitably proportioned, to supply one-half of the excess or unbalanced load on the heavy side of the system. The dynamo supplies the other half of the excess current which comes in on the neutral wire, with the current supplied by the A section of the storage battery, and returns to the dynamo through the B half of the battery charging that section.

This proportion holds good for any degree of unbalancing; that is, that part of the battery on the heavily loaded side will send out one-half of the current in the neutral wire, and the other half will go through the part of the battery that is on the light load side of the neutral.

This arrangement, though apparently ideal in simplicity on paper, is not so attractive in practice, for the reason that a regulator is needed in conjunction with the battery in order to prevent it from exhausting itself when the load is heavy, or drawing too heavily from the line when it is light. Moreover, the two halves of the battery cannot be kept in equal condition, because one side would do more work than the other, unless the circuit could be unbalanced alternately, and equally on, first one side and then the other. This difficulty can be met, however, by exchanging the two sections at regular intervals, say once a week.

A more practical method of compensation is by means of what is commonly termed a "motor-balancer," but is more correctly a motor-compensator. This consists of two small motors exactly alike in all respects, their shafts rigidly coupled together and their armatures connected, one on each side of the neutral wire, as indicated in Fig. 663, where 120 lamps are represented on each side of the neutral wire. Here it is assumed that the motor armatures require one ampere to drive them, or 220 watts (110 watts each), and for simplicity the current required by their field windings is ignored. So long as the load is balanced, the two armatures will take current from the main wires only. and will revolve idly. If more load is added to one side, however, or some load taken off the other side, the equilibrium between the voltages of the two sides will be upset; the voltage at the brushes of the motor on the lightly loaded side will be higher than that at the brushes of its mate, and it will drive the latter at a speed beyond that due to the circuit voltage, making a dynamo of it, and forcing it to carry the unbalanced part of the heavier load on the circuit. This is illustrated in Fig. 664, where 120 lamps are shown on one side and 60 on the other, each of the circles representing 10 lamps, taking ½ ampere each. What causes the distribution of current shown is this: When the load in the B division is reduced the voltage rises, because the losses in the dynamo and circuit wires are reduced; the voltage between the neutral and the negative wires rises more than that between the positive and neutral, because the resistance there is higher—all the reduction of load has occurred in that division of the circuit. The armature B, therefore,

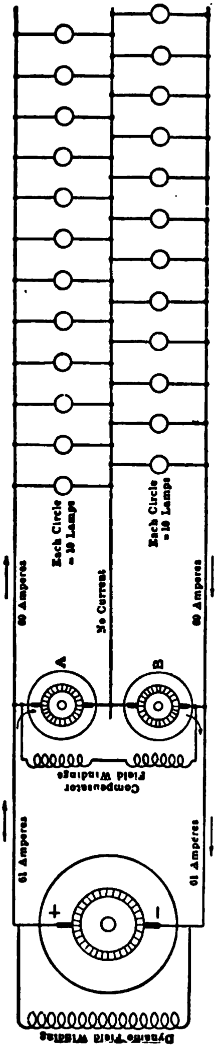


FIG. 663

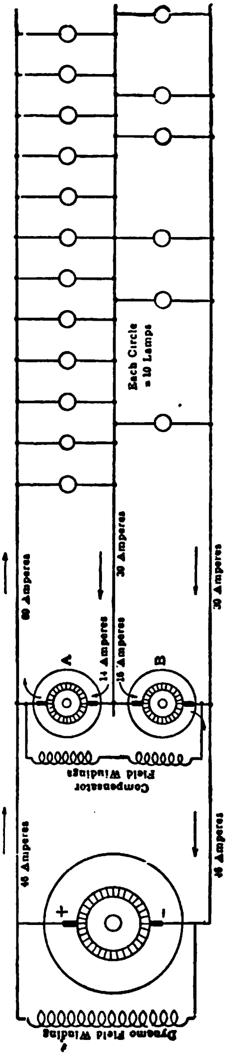


FIG. 664

speeds up, dragging the armature A with it until the voltage of the latter increases above that of its side of the circuit sufficiently to carry half of the excess load on that side, minus the power required to drive the two machines. This power was assumed to be 220 watts; the current taken by the two armatures in series in Fig. 663 being one ampere and the total voltage 220. Here, one of the armatures does all the work, so that the whole 220 watts must be applied to it, in addition to an amount of power equal to that being delivered by the armature A working as a dynamo. As the armature B takes its current now from the unbalanced current coming in on the neutral wire, it works at 110 volts and therefore requires 2 amperes to overcome the losses in the two machines (the losses in the windings are ignored to simplify the problem); the neutral wire must carry 30 amperes because the 60 lamps in the negative division will pass only 30 amperes. Deducting the 2 amperes for motor losses leaves 28 amperes, which divides between the two machines, 14 amperes supplying the motor with the energy necessary to produce 14 amperes from the armature now driven as a dynamo.

Another way to arrive at the division of current is as follows: The main dynamo must supply all of the energy represented in the circuit; all that the compensator does is to transfer the surplus energy from one side of the circuit to the other—it cannot supply any additional energy because it is driven by energy taken from the main circuit. Now the lamps take each ½ ampere at 110 volts, or 55 watts; there are 180 lamps, requiring $180 \times 55 = 9900$ watts. The compensator requires 220 watts to overcome its no-load losses, the extra losses at load being ignored for the present. The lamps and compensator together, therefore, require $9900 + 220 = 10{,}120$ watts. Ignoring line losses, the generator works at 220 volts, and in order to deliver 10,120 watts it must deliver 10,120÷220=46 amperes. Since the lamps in the positive division (A) require 60 amperes, the armature A working as a dynamo must supply 60—46=14 amperes. Consequently, of the 30 amperes in the neutral wire, 14 must have been generated in the little machine; the other 16 pass through the motor armature B to the main dynamo, as prevously explained.

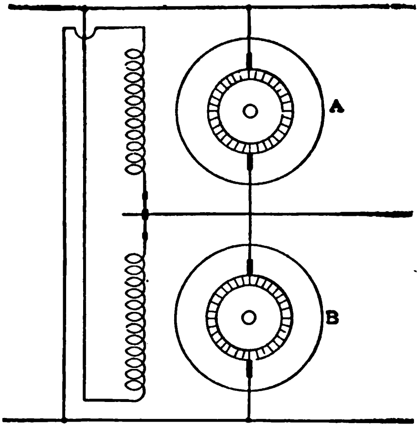


FIG. 665

The exact figures in practice would not be those here stated because the line losses, the current in the field windings of the compensator, and the losses in their armature windings affect the current distribution. The principle, of course, is not affected; the machine on the lightly loaded side of the system always runs as a motor, and drives its mate as a dynamo, the latter supplying about one-half of the difference between the two divisions of the load, minus the power required to drive the machine. The losses do affect the voltage regulation, however. If the armature windings of the compensator are of very low resistance, the voltages on each side of the neutral will be kept almost exactly equal; if the armature resistances are high, the voltage between the neutral and the main wire which carries the heavier load will be appreciably lower than that on the other side of the system.

The regulation obtained with motor compensators can be much improved by cross-connecting the field windings, as shown in Fig. 665. The result of this is that when the load on the side A, for example, is less than that on the other side, the voltage of the side A being higher than that of the side B, the field strength of the machine A will be weaker than that of the machine B, and its speed will be higher than it would be with a steady field. The machine B, on the other hand driven as a dynamo, will have its field strengthened, and will deliver a higher voltage than it would otherwise. In other words the machine that runs as a motor runs at a higher speed, thus giving its mate a higher voltage, and the latter will also have a stronger field, increasing its voltage still more, with the connections as shown, in Fig. 665, than with the arrangement shown in Figs. 663 and 664. The armature capacity of a motor balancer in amperes, must be equal to one-half of the current that will flow in the neutral wire when the system is out of balance by the maximum amount possible under operating conditions, plus the current required to overcome all losses in the two armatures at full load. The losses in small armatures range from 5 to 10 per cent at full load; therefore if the armatures of the balancer can carry 55 per cent of the maximum current that is likely to ever flow through the neutral wire they will be large enough.

ARC LAMPS.

When two rods of carbon are connected to a source of current, and their ends brought into contact with each other, and then separated a slight distance, the current will continue to pass across the interval, but an intense heat is generated, and the space between the ends of the carbon rods is filled with carbon vapor, and minute particles. The current passes over this space in a bow-shape path or arc, and it is from this fact that the lamp gets its name. The arc is constantly moving, and generally revolves around the carbon points. This can be easily seen by looking closely at a burning lamp through a smoked glass. After a lamp has been burning for some time on direct current the carbons assume the shape shown in Fig. 666, the upper or positive carbon assuming a cup shape, while the lower carbon generally burns to a point. This cup shape formation

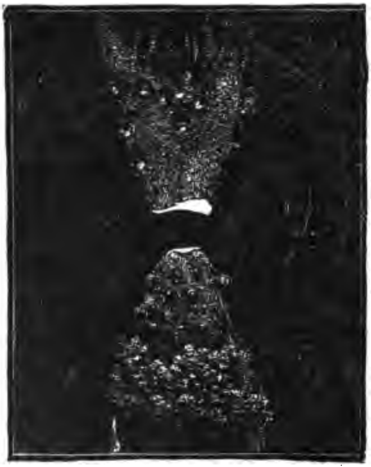


FIG. 666

on the upper or positive carbon acts as a reflector to throw the light downward. The positive carbon burns away about twice as fast as the negative carbon, and lamps must be trimmed accordingly. Sometimes the current feeding arc lamps (on direct current systems) becomes reversed, either through the dynamo reversing its polarity or through wrong plugging of the switchboard. The lamps will now burn "upside down," or, in other words, the bottom carbon will be the positive one. In such a case, if let go, the carbon holders of the lamp will be burned and the lamp will burn for only half the time for which it was intended, owing to the fact that the lower or negative carbon is only

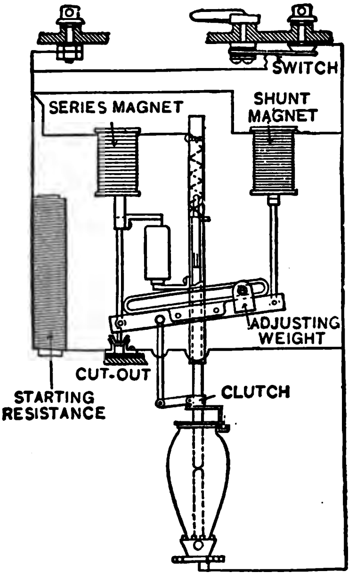


FIG. 667

DIAGRAM OF CONSTANT-CURRENT SERIES ARC LAMP MECHANISM.

one-half as long as the upper or positive carbon. Such a condition can be determined by either of the following ways: See if the light is being thrown downwards. See which carbon is burning away the faster. Raise the carbons and notice the formation of the carbon tips. When the carbons are separated it will be noticed that the tip of one carbon is considerably hotter than the other, and is heated a longer distance from the point; this is the positive carbon.

The heat of the arc is very intense, that of the positive pole being 7200° Fahr. and the negative 5400° Fahr. Fig. 667 illustrates the action of a constant current or series arc lamp. It shows the lamp inactive, the carbons in contact, and the cut-out closed. If current is turned on, it goes through the cut-out. In series with the cut-out is a coil which provides the starting resistance. Its resistance shunts sufficient current through the series magnet to cause it to attract its armature and raise the clutch. This separates the carbons, the arc strikes, and the current is shunted through the shunt magnet. This at once begins to regulate the length of the arc.

The armatures of the shunt and series magnets operate a rocker arm which is pivoted between the magnets, so that the series and shunt magnet have reverse effects on the movable upper carbon. As the shunt-magnet armature is drawn up, the clutch descends, owing to the action of the rocker arms, and the reverse action takes place when the shunt-magnet armature descends. In this way the increase of arc length, shunting more current through the shunt magnet, causes the clutch to descend and the arc shortens. The dash-pot is shown to the left of the central tube above the rocker arm. Immediately below the clutch is the tripping platform, seen extending over the top of the globe.

Adjusting Weight.—This slides back and forth upon the rocker arm attached to the two armature rods. This is fastened in any desired position by a setscrew. For variations in current exceeding 0.2 ampere above or below the rated current of the lamp, the weight must be shifted. By moving the weight toward the clutch rod the voltage is reduced, and moving at away from the clutch rod increases the voltage.

Fig. 668 shows a diagram of connections for the improved Brush arc lamp. These lamps are used on constant current, or series systems, and their action is as follows:

The carbons should rest in contact when the lamp is cut out. When the switch is opened, part of the current from the positive terminal hook P goes through the adjuster to the yoke, and thence through the carbon rod and carbons to the negative terminal hook N. The remainder of the current goes to the cut-out block, but, as the cut-out block is closed at first, the current crosses over through the cut-out bar to the starting resistance, and so to the negative side of the lamp. A part of it, however, is shunted at the cut-out block through the coarse wire of the magnets, and so to the upper carbon rod and carbons and out. This shunted current energizes the magnet, and so raises the armature which opens the cut-out, and at the same time establishes the arc by separating the carbons.

The fine wire winding is connected in the opposite direction from the coarse wire winding, and its attraction is therefore opposite. When the arc increases in length, its resistance increases, and consequently the current in the fine wire is increased. The attraction of the coarse wire winding is therefore partly overcome, and the armature begins to fall. As it falls, the arc is shortened and the current in the fine wire decreases. The mechanism feeds

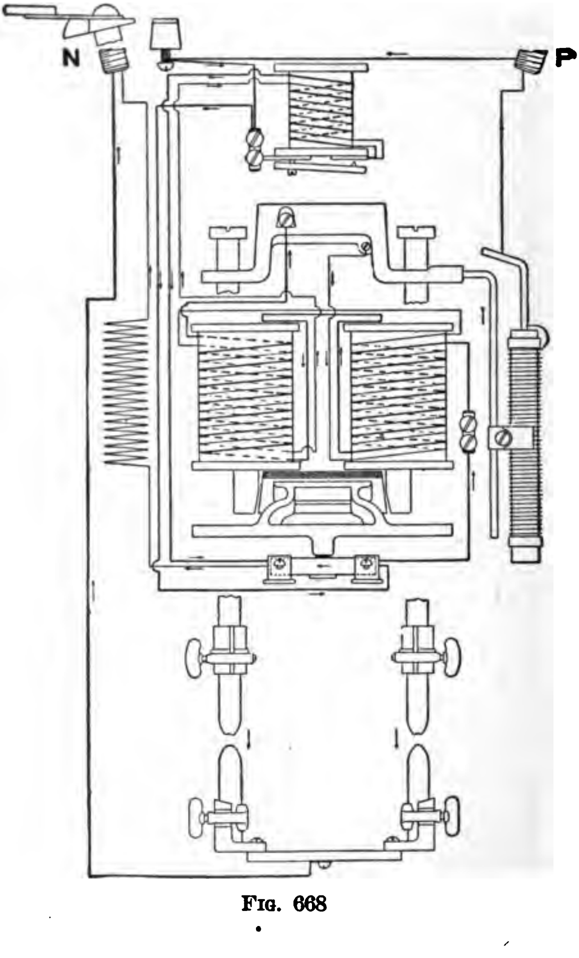


FIG. 668

the carbons, and regulates the arc so gradually that a perfect, steady arc is maintained.

The fine wire of the magnets is connected in series with the winding of a small auxiliary cut-out magnet at the top of the mechanism.

This magnet, which also has a supplementary coarse winding, does not raise its armature unless the voltage at the arc increases to 70 volts. The two windings connect at the inside terminal on the lower side of the auxiliary cut-out magnet, and the current from the fine wire of the main magnets passes through both windings and then to the cut-out block, and so to the starting resistance and out.

If the main current through the carbon is interrupted (as by breaking of the carbons) the whole current of the lamp passes through the fine wire circuit. Before this excessive current has time to overheat the fine wire circuit, it energizes the auxiliary cut-out magnet, and closes a circuit directly across the lamp through the coarse wire on the auxiliary cut-out to the main cut-out block, and thence to the negative terminal.

The auxiliary cut-out operates instantly, and prevents any danger to the magnets during the short period required for the main armature to drop and throw in the main cut-out. When the main cut-out operates, the armature of the auxiliary cut-out falls, because there is not sufficient current in that circuit to energize the magnet.

The voltage at which the auxiliary cut-out magnet operates depends on the position of its armature, which is regulated by the screw securing the armature in position. It should be adjusted to operate at not less than 70 volts.

One of the three methods of suspension may be used for Brush lamps. If chimney suspension, which is the most common, is adopted, the wire, cable or rope used to suspend the lamp must be carefully insulated from the chimney. For this purpose a porcelain insulator should be inserted between the support and the lamp, as shown in Fig. 669.

Hook suspension may be used to advantage in some places, but great care must be taken to insulate the supporting wires from any conductors, as the hooks form the terminals of the lamps.

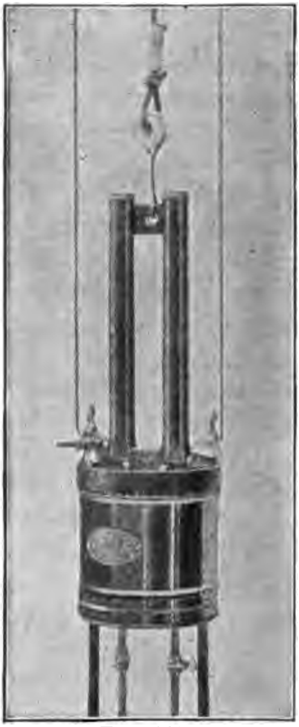


FIG. 669

The most convenient arrangement for indoor use is to suspend the lamp from a hanger board. The porcelain base of the hanger board prevents short circuits or grounds.

A protecting hood is not necessary for outdoor use, as the lamp chimney and its base are one casting and effectually exclude rain or snow.

The lamps run on circuits of 6.6 amperes for 1,200 and 9.6 amperes for 2,000 nominal candlepower. In case it is necessary to run a lamp on a circuit differing from the standard, the lamp may be adjusted by moving the contact on the adjuster. About one ampere either above, or below the normal may be compensated for by this means.

Permanent adjustment for special circuits of variation greater than one ampere is made by filing the soft iron armature. The clutch should be so adjusted that the center of the armature is $\frac{13}{16}$ in. above the plate when the trip on the first rod is touching the bushing, and $\frac{11}{16}$ in. when the trip on the second rod is in a similar position. A small gauge is convenient for adjusting the clutch. The position of the trip of the clutch determines the feeding point of the lamp.

After thoroughly repairing and cleaning the lamp, it should be run a short time before installing. Lamps should not be tested in an exposed place, as a strong draft of air will cause unpleasant hissing which may be mistaken for some internal trouble.

Lamps should not hiss or flame if good carbons are used. A voltmeter should always be used when adjusting or testing.

The lamp terminals are marked P (positive) and N (negative) and should be connected into circuit accordingly.

The carbons should be solid and of uniform quality. For the best results, the upper carbon should be 12 in.$\times\frac{7}{16}$ in., and the lower 7 in.$\times\frac{7}{16}$ in. The stub of the upper carbon may then be used in the lower holder when retrimming.

At each trimming the rod should be carefully wiped with clean cotton waste. If any sticky or dirty spots appear, which cannot be readily removed with waste, use a piece of well-worn crocus cloth, always being careful to use a piece of clean waste before pushing the rod into the lamp.

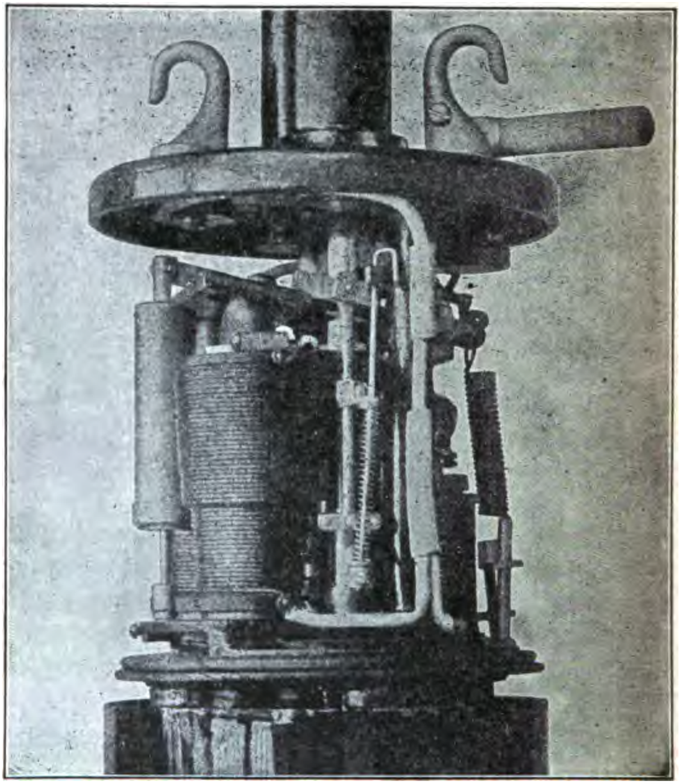


FIG. 670

It should never be pushed up into the lamp in a dirty condition.

The carbon rod may be unscrewed and removed with a small screw driver, or small strip of metal inserted in the slot cut in the rod cap. The cap will remain in the hole through the yoke when the rod is taken out.

In Fig. 670 an interior view of the Thomson-Houston arc lamp is shown. This lamp is also used on constant current systems.

The lamps should be hung from the hanger boards provided with each lamp, or from suitable supports of wire or chain.

As the hooks on the lamp form also its terminals, they should be insulated, where a hanger board is not used, from the chains or wires used to support the lamp.

When the lamps are hung where they are exposed to the weather, they should be covered with a metal hood, to prevent injury from rain and snow.

In such cases, care should be taken that the circuit wires do not form a contact on the metal hood and short circuit the lamp.

Before the lamps are hung up they should be carefully examined to see that the joints are free to move, and that all connections are perfect.

No lamp should be allowed to remain in circuit, with the covers removed and the mechanism exposed. Such practice is dangerous, and in violation of insurance rules.

The object of testing the lamps in the station is to find any defects, if such exist, and to test all the conditions of running, before delivering them to customers. The lamps should not be hung up in their respective places in the external circuit, until everything is running with perfect satisfaction.

The tension of the clamp which holds the rod is adjusted by raising or lowering the arm at the top of the guide rod. (See Fig. 671.) If the tension is too great the rod and clutch will wear badly, and the feeling will be uneven, causing unsteadiness in the lights. Too little tension will not allow the clutch to hold up the rod, and any sudden jar to the lamp will cause the rod to fall and the light to go out.

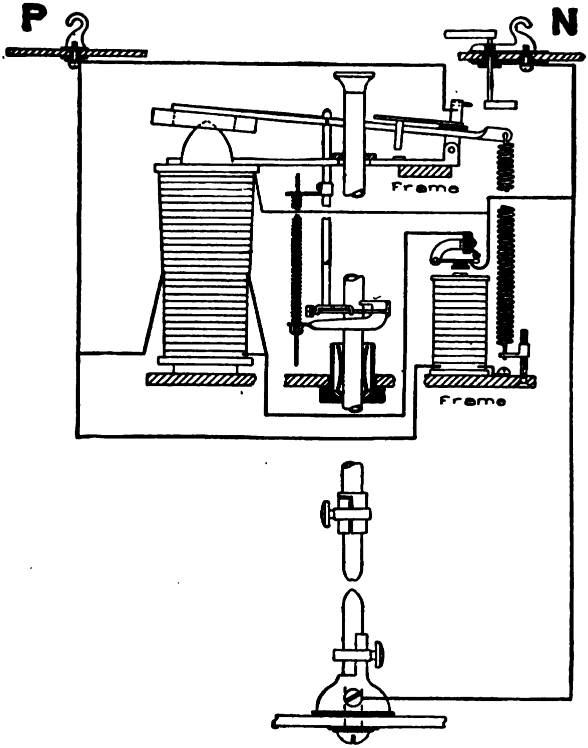


Fig. 671

The double carbon, or M lamp, should have the tension of the second carbon a trifle lighter than the first one.

When adjusting the tension, be sure to keep the guide rod perpendicular and in perfect line with the carbon rod; it should be free to move up and down without sticking.

The tension of the clutch in the D lamp should be the same as that of the K lamp. It is adjusted by tightening or loosening the small coil spring from the arm of the clutch to the bottom of the clamp stop.

To adjust the feeding point in the K lamp, press down the main armature as far as it will go, then push up the rod about one-half its length, let go the armature and then press it down slowly and note the distance of the bottom side of the armature above the base of the curved part of the pole. When the rod just feeds, this distance should be 1/4 in. If it is not, raise or lower the small stop which slides on the guide rod passing through the arm of the clutch, until the carbon rod will feed when the armature is 1/4 in. from the rocker frame at base of pole.

To adjust the feeding point of the M lamp, adjust the first rod as in the K lamp. Then let the first rod down until the cap at the top rests on the transfer lever. The second rod should feed with the armature at a point 1/16 in. higher than it was while feeding the first rod, that is, it should be 5/16 in. from rocker frame at base of pole.

The feeding point of the D lamp is adjusted by sliding the clamp stop up or down, so that the rod will feed when the relative distances of the armatures of the lifting magnet, and the armature of the shunt magnet from rocker arm frame arc in the ratio of 1 to 2. There should be a slight lateral play in the rocker, between the lugs of the rocker frame.

The armatures of all the magnets should be central with cores, and come down squarely and evenly. There should be a separation of $\frac{1}{32}$ in. between the silver contact points, when the armature of the starting magnet is down. This contact should be perfect when the armature is up. The arm for adjusting the tension should not touch the wire or frame of the lamp when at the highest point. There should be a space of $\frac{3}{32}$ in. or $\frac{1}{8}$ in. between the body of the clutch and the arm of the clutch, to allow for wear on the bearing surfaces.

Always trim the lamp with carbons of proper length to cut out automatically, that is, have twice as much carbon projecting from the top as from the bottom holder. Always allow a space of $\frac{1}{4}$ in., when the lamp is trimmed, from the round head screw in the rod, near the carbon holder, to the edge of the upper bushing, so that there will be sufficient space to start the arc.

The arcs of the 1,200 candlepower lamps should be adjusted to 3/64 in., with full length of carbon. Arcs of 2,000 candlepower lamps should be adjusted from $\frac{1}{16}$ to $\frac{3}{32}$ in. when good carbons are used.

The action of a lamp that feeds badly may often be confounded with a badly flaming carbon. The distinction can readily be made after a short observation. The arc of a lamp that feeds badly will gradually grow long until it flames, the clutch will let go suddenly, the upper carbon will fall until it touches the lower carbon, and then pick up. A bad carbon may burn nicely and feed evenly until a bad spot in the carbon is reached, when the arc will suddenly become long and flame and smoke, due to impurities in the carbon. Instead of dropping, as in the former case, the upper carbon will feed to its correct position without touching the lower carbon.

In a series arc lamp the shunt coil is used to regulate the voltage over the arc. With constant potential arc lamps this shunt coil is not needed, owing to the fact that the voltage over the lamp is practically constant. Fig. 672 shows a diagram of an arc lamp for use on constant potential circuits. The upper carbon is supported by means of an iron yoke which forms a core to the two solenoids M M. Current entering binding posts T passes through the windings of these two solenoids and then through the carbons and through the resistance coil R to the other terminal of the lamp. The action of the lamp is as follows: Current passing over the solenoids M M is regulated by the resistance across the arc. This current produces an electromagnetic pull on the iron core and floats, magnetically, the core and upper carbon. When the carbons burn away at the crater the distance from point to point of the carbons is increased, and a corresponding increase in resistance to the flow of the current takes place. This reduces the flow of

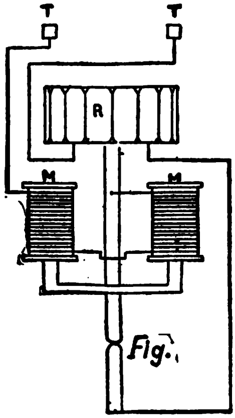


FIG. 672

current around the solenoids and correspondingly reduces the electromagnetic pull on the core; the iron core and carbon fall a slight distance by gravity. In so doing the distance at the crater is decreased and the flow of current increased, and a corresponding increase in resistance to the solenoids and drawing up the core and carbons. In this way a very nice equilibrium between gravity and magnetic pull is maintained. It will be noticed that this lamp has no automatic cut-out as has the constant current arc lamp. In a series arc lamp when the carbons are all consumed, the automatic cut-out closes the circuit from the positive and negative binding posts of the individual arc lamp, thereby maintaining a path through the arc lamp over which the current can continue to flow to supply the remaining arc lamps in the series circuit.

The series arc, as its name would indicate, is the most simple of all lighting circuits. The lamps are arranged so that all the current from the positive pole of the dynamo goes through each, and from the last on the conductor leads back to the dynamo. The series system is more generally used where it is desired to illuminate a large district, as in street lighting. It is also used to some extent in store lighting, although the series arc is fast being replaced with the constant potential arc for this purpose.

In the low tension or constant potential arc lamp the use of a cut-out mechanism is not necessary, because these lamps burn singly across the system of wiring, where a constant potential is maintained, and hence when the carbons are all consumed, current simply ceases to flow across them. In the open arc lamp the potential across the crater is usually from 45 to 50 volts, while in the inclosed arc lamp the potential across the crater is from 68 to 75 volts. This is due to the increased resistance through the crater, because of the peculiar nature of the gases emitted from the crater burning in a condition with practically no atmosphere. When such an arc lamp is connected across a 110 volt circuit, the lamp contains a resistance coil in the mechanism box over which the current must flow before producing the arc, see R. Fig. 672. This resistance coil assists to reduce the pressure from 110 volts to the pressure required by the arc or crater. If, for instance, the electromotive force across the wires supplying current to a low tension arc lamp is 110 volts, and the pressure required to maintain the arc or

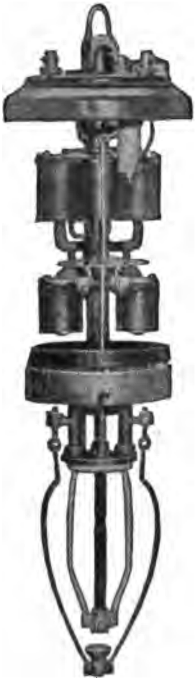


FIG. 673

crater is 70 volts, then the resistance coil chokes down the electromotive force from 110 to 70, or 40 volts. If the arc consumes 4 amperes of current then the loss is 4 (amperes) times 40 (volts), or 160 watts. This 160 watts is lost by heat radiating to the atmosphere from the wire of the resistance coil. The constant potential lamp is usually referred to as the low tension arc lamp. The high tension arc lamp generally burns with the arc in the open air, while the low tension lamp burns with the arc encased in a small glass bulb so arranged as to permit the upper carbon to slide into the bulb in a manner that will maintain, as near as possible, a condition whereby the arc burns in a gas containing no oxygen. The enclosed arc lamp has the advantage of burning a considerable number of hours without being recarboned or trimmed; but it also has the disadvantage that the bulb enclosing the arc turns black after burning for some time, caused by the gases emitted from the arc. This renders the bulb partially opaque, consequently imprisoning a considerable quantity of useful light. Enclosed arc lamps are also operated in series systems, and where they are so used the objection of loss due to the cutting down of the voltage (as in constant potential lamps) is overcome. Enclosed lamps are also operated on alternating current systems.

The operation of the alternating current arc lamp, and the mechanism in the lamp is very similar to that of the direct current arc lamp, but the magnets instead of being constructed of solid iron are laminated in a manner similar to the system of lamination explained in the construction of armatures. These laminated cores, and other parts forming the magnetic circuit in the arc lamp are necessary to avoid eddy currents. The crater has neither a cup shape on the upper carbon, nor a point on the lower carbon, because current flows through the crater alternately positive, and negative with each alternation. In the alternating arc lamp the upper and lower carbons burn away with almost equal rapidity, and the same quantity of light is projected upward as downward.

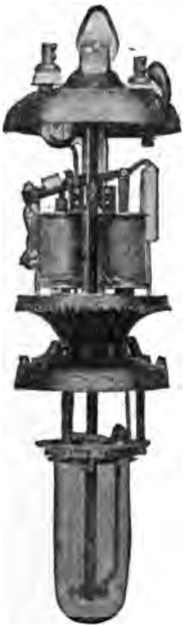


FIG. 674

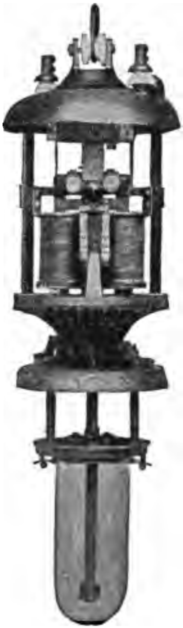


FIG. 675

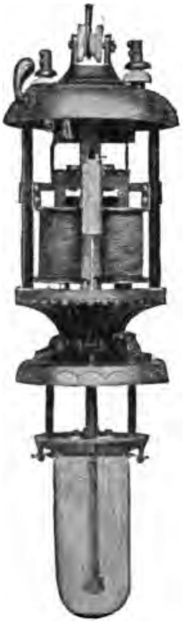


FIG. 676

In Fig. 673 is shown an arc lamp with the case removed. The two upper coils are the coarsely wound series coils, while the two lower coils are the finely wound shunt coils. This lamp is adapted for an enclosed arc bulb. The magnetically attracted cores are U shaped, and both cores are connected together mechanically by non-magnetic metal, such as brass or zinc, so that the magnetism set up in the shunt coils will not be affected by the magnetism set up by the series coils. This scheme is used in alternating current lamps, while in direct current lamps the cores are made of H shaped iron not laminated.

In Figs. 674 to 676 are shown three views of series enclosed, alternating current arc lamps of the Western Electric Company.

Fig. 674. Side view of lamp, showing one series and one shunt spool, lever movement and adjusting weight. This weight is fastened upon a threaded rod, and the finest adjustment can be obtained by screwing the weight backward or forward. Threads can be clamped in position when the correct adjustment is obtained.

Fig. 675. Front view of lamp, showing shunt spools, supporting resistance and cut-out. Note that lever carries no current when in normal working position, but that insulated bridge forms connection across two contacts, completing cut-out circuit when in position shown in cut.

Fig. 676. Rear view of lamp, showing series spool, short circuiting switch, and manner of suspending dash-pot. Note that the dash-pot is inverted, allowing such dirt as may accumulate therein to fall out, rather than in the dash-pot.

The three cuts show the manner of suspending the spools and their accessibility, it being possible to remove any spool by simply taking out the two screws which fasten it to the frame, and lifting it off the lower support.

The carbons used in arc lamps are extremely hard and dense. They are made from a mixture of powdered gas house coke, ground very fine, and a liquid like molasses, coal tar, or some similar hydro-carbon, forming a stiff, homogeneous paste. This is molded into rods or pencils of the required size and length, or other shapes, being solidified under powerful hydrostatic pressure. The carbons are now allowed to dry, after which they are placed in crucibles or ovens, thoroughly covered with powdered carbon, either lampblack or plumbago, and baked for several hours at a high temperature. After cooling, they are sometimes repeatedly treated to a soaking bath of some fluid hydrocarbon, alternated with baking, until the product is dense as possible, all pores and openings having been filled solid. Arc carbons are often plated with copper by electrolysis, to insure better conductivity.

It is said that one 2,000 candlepower arc lamp will light in open yards 20,000 sq. ft.; in railroad stations, 14,000 sq. ft.; in foundries and machine shops, 5,000 to 2,000 sq. ft. Where good, even illumination is desired, it is advisable to use a greater number of smaller lamps evenly distributed.

THE INCANDESCENT LAMP.

One of the fundamental laws of electric supply is, that the resistance in an electric circuit should be concentrated at the point where energy is to be developed, and the incandescent lamp is a good expression of this law, as the useful resistance is that which is afforded by the filaments of the lamp. The incandescent lamp comprises a carbon filament enclosed in a glass bulb from which the air has, as far as possible, been withdrawn, the carbon filament being soldered to the ends of small platinum wires entering the glass shell. Incandescent lamps can be burned either in series or in multiple; the multiple system being the most used. Series incandescent lamps are used to a considerable extent in the smaller towns for street lighting and also for the small miniature lamps burned in series on a constant potential system, and used for decorative purposes. They are also used in street car lighting.

When incandescent lamps are to be used in series, they should be carefully selected; there is quite a difference in the current consumed by different lamps, even of the same make, and when they are all limited to the same current quite a difference in candlepower may be noticeable. Some will be above their rated candlepower and others below.

The resistance of an incandescent lamp when cold is very high, varying in the ordinary 16 candlepower 110 volt lamp from 600 to 1,000 ohms. When the lamp becomes heated, as when current is passing through it, the resistance reduces considerably, being in the 16 candlepower 110 volt lamp about 220 ohms.

The current required by the various incandescent lamps varies considerably for lamps of the same voltage and candlepower, but a good average which can be used in figuring currents is ½ ampere for a 16 candlepower 110 volt lamp and ¼ ampere for the 220 volt 16 candlepower lamp. The amount of power, in watts, consumed by a lamp is equal to the voltage multiplied by the current, or $W = C \times E$. A 16 candlepower 110 volt lamp taking ½ ampere would consume $110 \times \frac{1}{2} = 55$ watts, while a 220 volt lamp taking ¼ ampere would consume $220 \times \frac{1}{4} = 55$ watts. It will thus be seen that while the current and voltage may vary, the amount of power consumed will be approximately the same for all 16 candlepower lamps. Lamps are rated at a certain number of watts per candle, the amount varying from 3 to 4 watts for 16 candlepower 110 volt lamps. The proper lamp to be used varies according to the conditions. While less power is consumed in a 3.1 watt lamp, the life of the lamp is comparatively shorter, so that the lamps will have to be renewed oftener. With a 4 watt lamp a greater amount of current is consumed, but the life of the lamp is longer. Another point of great importance in burning incandescent lamps is the voltage. The table below shows what effect variation in voltage has on the candlepower and efficiency.

An increase in voltage increases the candlepower. This increases the efficiency and shortens the life as follows:

A lamp burning at—

Normal voltage gives 100 per cent. C. P. and consumes 3.1 Watts per C. P.
1% above normal gives 106% C. P. and consumes 3. Watts per C. P.
2% above normal gives 112% C. P. and consumes 2.9 Watts per C. P.
3% above normal gives 118% C. P. and consumes 2.8 Watts per C. P.
4% above normal gives 125% C. P. and consumes 2.7 Watts per C. P.
5% above normal gives 132% C. P. and consumes 2.6 Watts per C. P.
6% above normal gives 140% C. P. and consumes 2.5 Watts per C. P.

A lamp burning at normal voltage should give its full candlepower at its rated efficiency. A 3.1 watt lamp burning below its voltage loses its efficiency and candlepower as follows:

If burned—

1% below normal it gives 95% C. P. and consumes 3.2 Watts per C. P.
2% below normal it gives 90% C. P. and consumes 3.35 Watts per C. P.
3% below normal it gives 85% C. P. and consumes 3.5 Watts per C. P.
4% below normal it gives 80% C. P. and consumes 3.6 Watts per C. P.
5% below normal it gives 75% C. P. and consumes 3.75 Watts per C. P.
6% below normal it gives 70% C. P. and consumes 4. Watts per C. P.
10% below normal it gives 50% C. P. and consumes 4.6 Watts per C. P.

By referring to the table it will be seen that with the voltage raised 3 per cent (on a 110 volt system to a little over 113 volts) the candlepower will increase 18 per cent, or in other words, a 16 candlepower lamp would be raised to nearly 19 candlepower. At the same time raising the voltage will decrease the life of the lamp. This is shown in the following table where, with an increase of 6 per cent in the voltage, the life of the lamp is reduced 70 per cent. A lamp at normal voltage has 100 per cent life.

The same lamp 1% above normal loses 18% life.
The same lamp 2% above normal loses 30% life.
The same lamp 3% above normal loses 44% life.
The same lamp 4% above normal loses 55% life.
The same lamp 5% above normal loses 62% life.
The same lamp 6% above normal loses 70% life.

To obtain satisfactory results, the voltage should be kept constant at just the proper value.

Considerable heat is generated in an incandescent lamp, so that as a general rule it is a bad plan to use paper shades which come very close to the bulb. Where lamps are hung so that there is a liability of their coming in contact with surrounding inflammable material, such as in warehouses and store-rooms, it is a good plan to enclose the lamp in a wire guard.

Table 59 will prove a handy reference for estimating the number of lamps (8 to 50 C. P.) that can be run per horsepower or kilowatt. The table is figured for theoretical values, so that the actual horsepower or kilowatts delivered must be used, or else values less than those given must be used to allow for loss in the lines.

TABLE 59

EFFICIENCY OF INCANDESCENT LAMPS.

Candlepower.	Efficiency.	Total Watts.	Per Horsepower.	Per Kilowatt.
8	3.5	28	26.6	35.7
8	4	32	23.3	31.2
16	3	48	15.5	20.8
16	3.1	50	14.9	20
16	3.5	56	13.3	17.8
16	4	64	11.6	15.6
20	3	60	12.4	16.6
20	3.1	62	12	16.1
20	3.5	70	10.6	14.2
25	3	75	9.9	13.3
25	3.1	77.5	9.6	12 9
25	3.5	87.5	8.5	11.4
25	4	100	7.4	10
32	3	96	7	10.4
32	3.1	99.2	7.5	10
32	3.5	112	6.6	8.9
50	3	150	4.9	6.6
50	8.1	155	4.8	6.4
50	8.5	175	4.2	5.7

The first column gives the candlepower. The second column gives the number of watts consumed for each single candlepower obtained, and is called the efficiency of the lamp. Multiply the total candlepower by the efficiency and you get the total number of watts consumed by the lamp. The fourth column shows the number of lamps per 746 watts, and the last column the number of lamps per 1,000 watts.

The current and watts consumed by 110 volt lamps of the different candlepowers are approximately given below.

4 candlepower	0.18 amperes,	20 watts.
8 candlepower	0.29 amperes,	32 watts.
16 candlepower	0.5 amperes,	55 watts.
32 candlepower	1.0 amperes,	110 watts.

The light given off by an incandescent lamp varies according to the position from which it is viewed. In some makes of lamps most of the light is given off directly downward, while in other lamps the maximum light is given off in a horizontal direction. The best lamp to use must be determined by the location of the lamp and the place where the light is required. By the use of suitable reflectors or shades the light can be thrown in any direction desired. A 16 candlepower lamp if placed seven feet above the floor will light up a floor space of 100 sq. ft., providing the walls are of a light color. If the walls are of a dull color, or if a bright illumination is desired more lamps should be used. Glass globes placed over the lamps reduce the light to a considerable extent, as is shown in the following table:

Clear glass	10 per cent.
Holophane	12 per cent.
Opaline	20 to 40 per cent.
Ground	25 to 30 per cent.
Opal	25 to 60 per cent.

PRIMARY BATTERIES.

There are many places where a small amount of electrical power is needed, but the amount is so small, that running a line to the point would not pay. In such cases primary batteries may be used to good advantage.

Construction.—If a piece of zinc, and a piece of copper be placed in a jar containing dilute sulphuric acid, and not allowed to touch each other below the surface of the liquid, but are connected above it, by a wire, a current of electricity will flow through the wire, and the wire will show magnetic qualities. This is one of the most simple forms of primary battery. The current flows from the copper to the zinc outside of the cell, and from the zinc to the copper in the liquid.

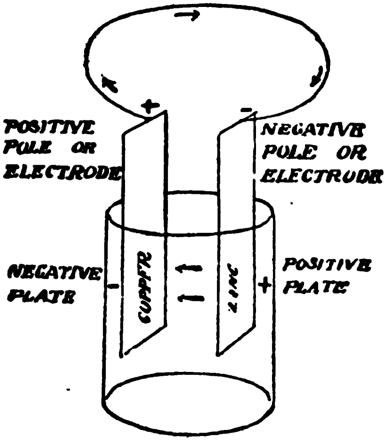


Fig. 677
NAMES OF PARTS OF CELL

Fig. 677 shows a cell such as described above giving names of the different parts. The zinc plate slowly dissolves, and more or less hydrogen gas is thereby set free, which arises in the form of bubbles. Carbon has been found to be a good substitute for copper, in the makeup of battery cells. The different types of cells are classified as follows:

Open circuit: A cell designed for intermittent work. Periods of work short, intervals of rest long. Usually designed for small currents. When not in use these cells must be left on open circuit.

Semi-closed: A cell designed for fairly steady work. Periods of work long, intervals of rest short. Often designed to produce heavy currents. When not in use these cells must be left on open circuit.

Closed circuit: A cell designed for continuous work. Periods of work long, intervals of rest very short. Usually designed for very small currents. Almost impossible to design so as to produce much current. When not in use they must be left on closed circuit.

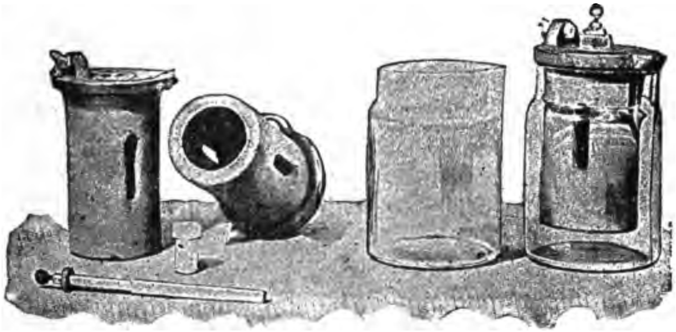


FIG. 678
CARBON CYLINDER CELL

Polarization prevented: Cell so designed that no hydrogen gas is produced by chemical action of cell.

Polarization cured: Cell produces hydrogen, but a chemical placed in the cell turns the hydrogen to water which is harmless.

Polarization delayed: Cell has very large and absorbent negative plate.

The Carbon Cylinder Cell.—These are sold under the name of Law, Samson, Hercules, etc. It is an open circuit, polarization delayed type. They give a pressure of 1.5 volts and have a resistance of 1 to 2 ohms. Two of them are shown in Fig. 678.

The carbon element is made with as large a surface as possible. Carbon and charcoal have a remarkable power of absorbing gases. A cubic inch of charcoal will condense and absorb 20 to 30 cubic inches of gas.

The zinc element is a rod and the fluid a strong solution of sal ammoniac in water. The scientific name of this chemical is ammonium chloride.

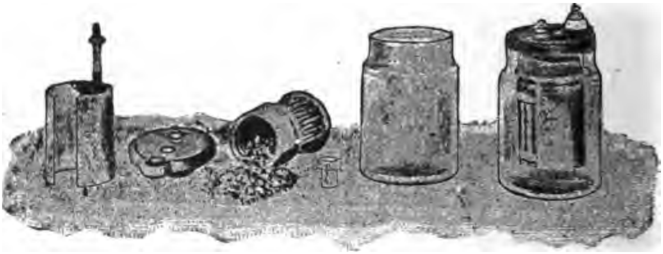


Fig. 679

CARBON CYLINDER CELL WITH DEPOLARIZER

The action of the cell dissolves the zinc, forming zinc chloride, which dissolves in the water. A little ammonia and hydrogen gases are set free. The ammonia is dissolved by the water and the hydrogen absorbed by the carbon.

In time the carbon gets soaked full of hydrogen, and to restore the cell it should be taken out and boiled in water for an hour.

These should only be used for call bells in offices or such unimportant work.

Leclanche Cell.—This is an open-circuit, polarization cured type. They are made in several forms. Voltage 1.5

and resistance 1 to 4 ohms. Uses sal ammoniac, zinc and carbon.

The carbon cylinder cell is sometimes modified to the Leclanche type by making the carbon element with a bottom and no opening in the sides. This carbon can, or bucket is filled with lumps of black oxide of manganese (manganese dioxide). The zinc is made in a cylindrical form, surrounding the carbon. This cell is shown in Fig. 679.

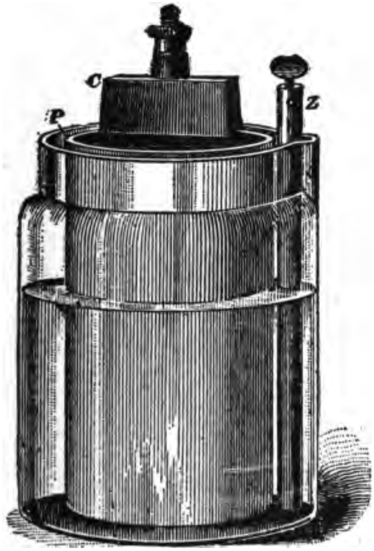


FIG. 680
ORDINARY LECLANCHE CELL

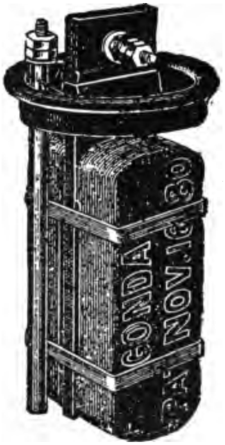


FIG. 681
ELEMENTS OF THE
GONDA-LECLANCHE CELL

The hydrogen is absorbed by the carbon but the manganese dioxide, being in contact with the carbon, gives up half of its oxygen to the hydrogen forming water, while it is reduced to manganese monoxide.

This cell is useful for call bell work, operating magnets on interlocking machines, running tell-tales on interlocking boards, and such other intermittent light work.

There is an older form of Leclanche cell shown in Fig. 680, where the carbon is placed in a cup of unglazed earthen ware (like a yellow flower pot) called a porous cup. The manganese is packed around the carbon slab. This form does not give such a large current as the cell in Fig. 679 because its resistance is high, often as much as four or five ohms.

A much used form of the Leclanche cell is the Gonda cell. The elements are shown in Fig. 681.

Here the manganese is powdered, mixed with cheap molasses, then by heat and pressure formed into slabs. These are attached to the carbon plates by rubber bands.

The bother and resistance of the porous cup is avoided.

The usual charge of a Leclanche type cell is a generous quarter pound of sal ammoniac dissolved in sufficient water to fill the jar two-thirds full after elements are in place.

The Gravity Cell.—This is a closed circuit cell with polarization prevented. It is very much used for telegraph circuits, operating the electrical devices in the lock and block signals, the motors in automatic signals and generally around interlocking plants. Its pressure is 1 volt and its current capacity rather low for its resistance is 3 or 4 ohms.

This cell is made in many forms called Bluestone cell, crow-foot battery, Lockwood cell, etc.

The parts of a gravity cell are shown in Fig. 682, and the assembled cell in Fig. 683.

The glass jars should be about 7 inches high and 6 inches in diameter. The zinc is cast in a shape so as to be easily suspended from the edge of the jar. The form shown is called a crow-foot zinc. It weighs about 3 pounds.

The copper element shown on left of Fig. 682 is made of three sheets riveted together at center and then spread out as shown. The rubber covered wire must be attached to the copper element by riveting. If soldered the joint would be eaten away by electrical action.

To set up a cell of ordinary size which holds about 0.8 gallons of liquid, make two solutions, one of copper, the other of zinc.

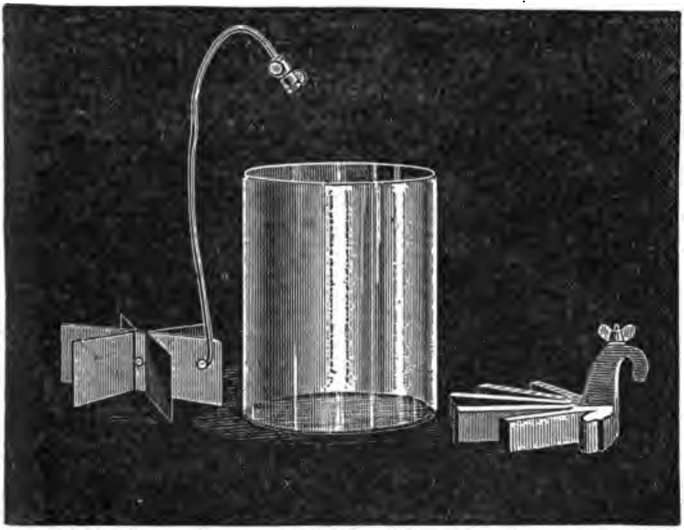


Fig. 682
ELEMENTS OF GRAVITY CELL AND JAR

Zinc solution: Pint and a half of pure soft water and 10 oz. of crystallized sulphate of zinc (white vitriol). Mix until dissolved and let it stand half a day in a glass jar.

Copper solution: Two and a half pints of soft water, 4 ozs. of crystallized sulphate of zinc, 8 ozs. crystallized sulphate of copper (blue vitriol). Mix and let stand a few hours in a glass jar.

Dip edge of battery jar for an inch in melted paraffin and let it cool.

Place the parts in jar as in Fig. 683 and pour jar nearly three-fourths full of the zinc solution. Place it at once in the spot where it is to be used and pour in the copper solution.

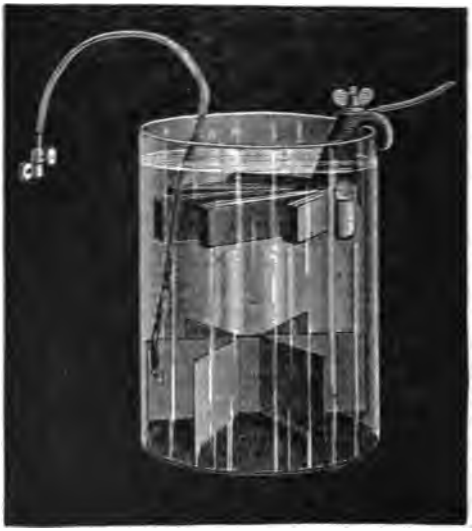


FIG. 683
GRAVITY CELL READY FOR USE

Insert a glass funnel in the top of a piece of ⅜-inch rubber tubing. Hold funnel so that lower end of the tube will be in the middle of the jar and just a little above the bottom.

Pour in the copper solution slowly until the copper element is completely covered. Place the cell into service immediately.

This cell will show a sharply defined line between the blue copper solution and the colorless zinc solution. This separation of solutions is essential to the cell's health. Leaving the circuit open for any length of time will allow the solutions to mix and spoil the cell.

The action of the cell is such that no hydrogen is permanently formed. The zinc is steadily dissolved into the zinc solution, setting free some hydrogen. This forms with the copper sulphate, sulphuric acid and metallic copper. The sulphuric acid dissolves more zinc, while the copper plates itself on the copper element at the bottom of jar.

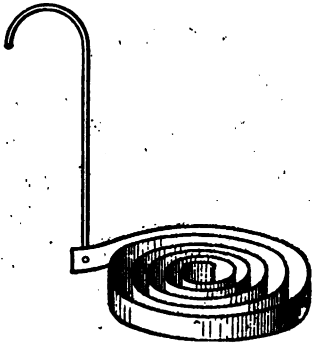


FIG. 684

LONG SERVICE COPPER ELEMENT FOR GRAVITY CELL

The zinc is consumed and the copper plate grows larger.

The effect of continued action is to increase the strength of the zinc solution so that it tends to settle to bottom of jar.

The copper being taken out, bit by bit, from the copper solution this latter gets lighter in weight and tends to rise being pushed up by the zinc solution.

If the blue solution of copper sulphate ever touches the zinc it will copper plate it at once. The cell will then have two copper elements and stop working.

Cells should be given some attention, and clever management will keep a gravity cell working continuously for an almost indefinite time.

As helps in the maintenance of cells two improvements have been made.

The form of copper element shown in Fig. 684 is better when heavy currents are not needed. It is a copper ribbon 4 feet long and ½ an inch wide, coiled like a clock spring. Zincs shaped like Fig. 685 are used until the prongs are all eaten off. A new one is then put in service and the old one jammed into the bottom of the new one as shown in Fig. 686.

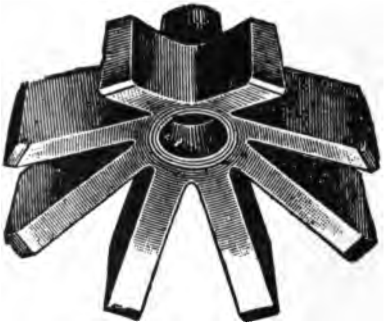


FIG. 685
D'INFREVILLES WASTELESS ZINC

These zincs are hung from a spring clip shown in Fig. 687, which lays across the top of the jar. The stud on the zinc makes a tight friction fit with the hole in the hanger, due to the springiness of the metal.

To keep cells in order a hard rubber syringe with the nozzle at right angles to barrel, holding about a pint, and a hydrometer should be obtained.

The hydrometer (Fig. 688) is a hollow glass float loaded with shot so as to float upright. The heavier a liquid the more of the stem sticks up above the surface.

These hydrometers are graduated on stem in actual specific gravities or in degrees Baume (pronounced Bomay). One with a stem about two inches long graduated from 15° to 40° Baume, or from 1.11 to 1.40 specific gravity, is best for battery work.

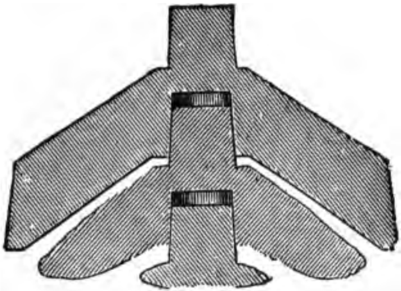


FIG. 686

USING UP OLD ZINCS

The first signs of exhaustion in the cell will be a fading of the deep blue color of the copper solution and a lowering of the line of separation between blue and white liquids.

When this occurs drop in about an ounce of copper sulphate in lumps. Be sure the lumps fall to the bottom. There will always be a lot of fine powder at the bottom of the copper sulphate barrel. Use this for making up new cells when possible. If too much accumulates for this purpose, make a saturated solution of it in water.

A saturated solution is one where the water has dissolved all it possibly can of the chemical, and leaves some yet undissolved on bottom of jar after repeated stirring.

Place this in cells showing signs of exhaustion in same way as the copper solution was placed in a newly set up cell.

The zinc solution should be tested as frequently as possible. Once in two weeks is not too often. Drop the hydrometer gently in. Should it read 1.15 draw some out with syringe and replace by fresh water.

Do not let it go below 1.10. If you have a Baume scale these numbers are 20 and 15 degrees. Throw all the removed zinc in a wooden tub, whether from working cells or from old cells, to be renewed.

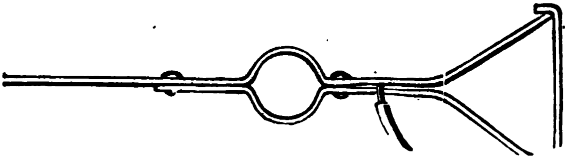


FIG. 687

Keep half a dozen pieces of metallic zinc in this tub. Any copper in this solution, mixed by cell's action, will turn to a reddish brown curd which can be filtered out. Reduce the clear liquid to 1.10 and use in making up new cells.

Watch your zinc. Should any brown hangers develop on it, detach them with a bent wire and let them fall to bottom of cell.

In time, in spite of all care, the zinc in a cell gets reddish brown all over. It is now time to give a complete overhauling.

Take the cell out of service. Syphon off zinc solution into the tub. Lift zinc out carefully and at once scrub clean with a wire brush. Wash and replace in another cell at once or dry thoroughly and keep dry until needed.

Syphon off the rest of the liquid into another wooden tub and use after filtering as copper solution to make up new cells.

Any lumps of copper sulphate in the bottom take out, rinse, and put in other cells.

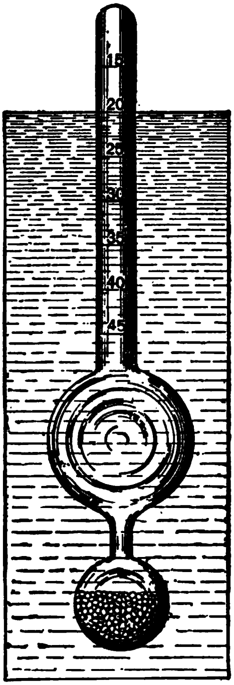


Fig. 688

HYDROMETER WITH BAUME SCALE

The mud in bottom of cells and in the zinc solution tub should be dried and sold to brass founders as "battery mud."

The copper plates taken from cells should be kept completely covered with water, wire and all, until needed again.

When they get too heavy and cumbersome sell them, as they are an especially pure form of copper.

Never leave gravity cell on open circuit; the liquids will mix.

The Fuller Cell.—Semi-closed circuit type, for heavy duty. Long periods of work with little rest.

Polarization cured. Pressure 2 volts, resistance 0.5 ohms. Cell shown in Fig. 689.

These cells are carbon and zinc, and since the chemical which converts the hydrogen to water will attack the zinc, a porous cup is used.

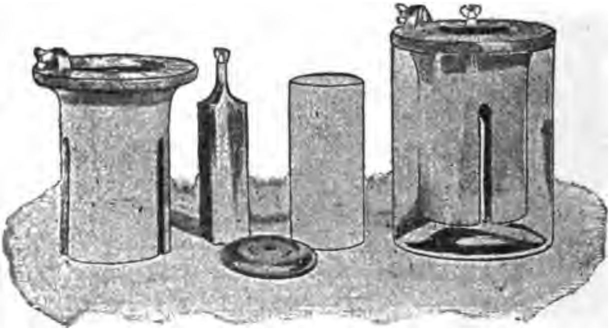


FIG. 689
FULLER CELL

The carbon or the zinc can be placed in the porous cup, but the zinc usually is. A tablespoonful of mercury is placed in bottom of porous cup, the zinc set in and the cup filled with very dilute sulphuric acid (1 acid, 50 water). The carbon is then placed in the outer jar, the porous cup being also in, and the outer jar filled three-quarters full of battery fluid or electropoin.

This is composed of 4 ozs. of bichromate of soda, 1¼ pints of boiling water, mixed and cooled; then while slowly stirring add little by little 3 ozs. sulphuric acid taken out of a carbon (not diluted). *Never pour water into acid.*

The bichromate of soda has so much oxygen in it that it will turn the hydrogen to water, changing itself to chromate of soda.

When the interior of the porous cup gets dark green colored a cup should be soaked in 1 to 50 acid for an hour and then mercury placed in bottom and zinc set in. Simply take out old cup and insert new one in its place.

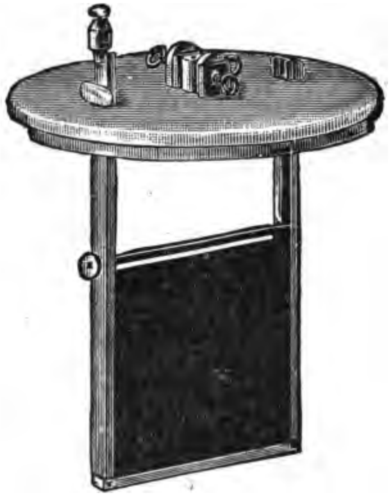


Fig. 690
OXIDE PLATE OF EDISON-LALANDE CELL

The old zinc should be cleaned, porous cup washed and then boiled in water and both placed in stock.

These cells should be left on open circuit when not in use. They are very powerful, but nasty to handle and not as cheap as the gravity cell. When the electropoin gets greenish it soon becomes exhausted, then throw it away. Cold battery rooms, or pits affect this cell less than the gravity cell.

Edison-Lalande Cell.—This is a semi-closed type with polarization cured. It has a resistance of 0.2 ohms and a very low voltage, 0.7, but is a bull dog for holding on. It will, when set up, start in to deliver a heavy current and keep at it until all its chemicals are used up. It needs no attention and is built so that you can not give any.

When it stops take out the copper and sell it, throwing everything else out. Clean up the jar and fit out again.

The cell uses zinc and oxide of copper plates immersed in a solution of caustic potash. The oxide plate is shown in Fig. 690 and the complete cell with a glass jar in Fig. 691. Porcelain jars are usually furnished.

The caustic potash comes in sticks sealed up in a tin can.

Place the elements in jar and fill with water to about one inch of the top. Take out the elements and put in the sticks of potash.

Stir constantly while dissolving, for it gets very hot and might crack the jar. Be very careful not to get caustic potash on your flesh. It not only burns terribly, but makes a wound which is very hard to heal.

If you buy potash by bulk, make the solution up to 1.33 on specific gravity scale or 38° on the Baume scale.

Place the zinc and copper oxide elements in the jar, seeing that they are properly separated by the hard rubber buffers. Pour the bottle of oil over the top of solution and place cover on.

If buying oil by bulk, get a heavy paraffin oil which will read 1.46 specific gravity or 48° Baume and pour a ¼ inch layer on each cell.

These are good cells, but any sulphuric acid or caustic potash cell is a nasty thing to handle.

The action of the cell dissolves the zinc, setting free hydrogen, which is changed to water by the copper oxide, which is reduced to pure copper by giving up the oxygen in it.

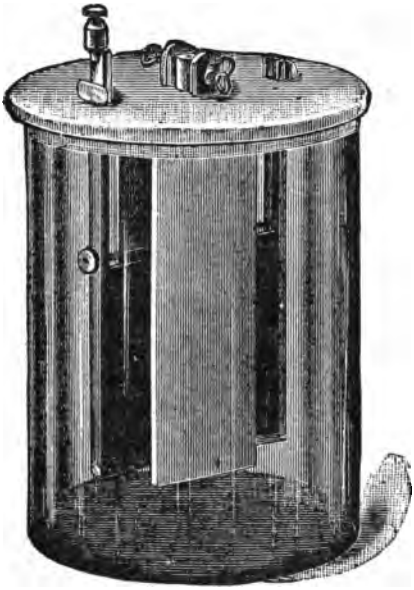


Fig. 691
EDISON-LALANDE CELL

Dry Batteries.—A dry battery is one which has its electrolyte disseminated through some solid material through which it can diffuse itself. Plaster of Paris and gelatinous compounds have been used for the solid part. The usual construction is on the basis of the plaster of Paris combinnation.

The outer cup is made of zinc, and acts as the positive electrode. Over it is slipped a strawboard tube. The object is to prevent the zinc of two batteries from touching each other so as to establish a wrong connection. The negative electrode is a plate of carbon. This is placed in the center of the zinc, and is so supported as not to touch it in any place. Carbon and zinc both carry binding posts. The filling varies. The following is used in the Burnley cell:

A wooden plunger or template, somewhat larger than the carbon, is inserted, and the following mixture introduced:

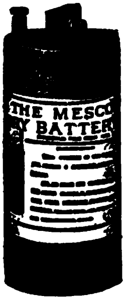


FIG. 692
DRY CELL

Ammonium chloride, zinc chloride, 1 part of each, plaster of Paris, 3 parts, flour 0.87 part, water 2 parts. After this has set a little, the wooden template is withdrawn, the carbon is inserted in the cavity left by its withdrawal, and the space left unfilled is filled with the following mixture. Ammonium chloride, zinc chloride, manganese binoxide, granulated carbon, flour, 1 part of each, plaster 3 parts, water 2 parts. The electromotive force of this cell is 1.4 volts, its resistance 0.3 ohm.

The Gassner dry cell has as negative a cylinder made of a mixture of carbon and manganese dioxide. The filling composition is as follows: Zinc oxide, ammonium chloride, and zinc chloride, 1 part each, plaster of Paris 3 parts, water 2 parts.

For the Meserole dry battery, there are mixed the following: Graphite, slacked lime, arsenious acid, and glucose or dextrine, 1 part each, carbon and manganese binoxide, 3 parts each. The mixture is finely pulverized and rubbed up in a saturated solution of ammonium chloride and sodium chloride (common salt) with one-tenth its volume of a solution of mercuric chloride and an equal volume of hydrochloric acid. These constituents are intimately mixed and poured into the zinc cup.

Dry batteries are sealed with pitch. A hole is sometimes left for the escape of gas.

STORAGE BATTERIES.

The storage cell is rapidly pushing the primary battery aside in signal and fire alarm work on account of:

(1) Its high voltage.

(2) Its great current capacity.

(3) The lowering of total battery expense if used for several years.

(4) Its steadiness of action.

Storage cells are used in train lighting to furnish light when train is not in motion, and to steady the supply of current.

They are used in some cases to furnish the power to operate switches on locomotives and motor cars.

In power houses they offer a reserve supply of power, and act as a steadier of the load on the generators.

The simplest storage cell would be two strips of lead immersed in dilute sulphuric acid. When current is sent through them one plate turns a dark brown color, and the other a grey color. After an hour's passage of current reverse the connection and charge the other way. The plates will change color—the grey one becoming brown and the other one grey.

If this charging first in one direction, and then in the other be kept up, you will notice that after each reversal of the current through the cell the acid is quiet but soon begins to gas or boil. This is the signal to reverse the current as the cell is charged.

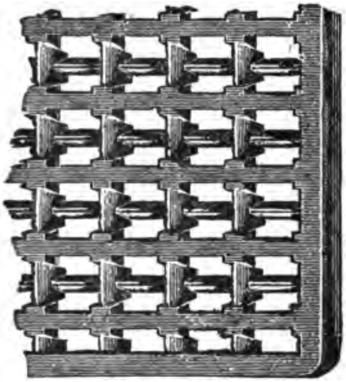


FIG. 693
LEAD GRID

When the cell takes several hours to gas it is in condition to use.

After one of the reversals continue to charge until cell has gassed about fifteen minutes. Remove the charging wires and connect to anything you wish to run. About 70% of the power you put into the cell can now be taken out.

You may now use this as a storage cell, charging it up till it gasses, and then using the accumulated electricity as you please.

You always lose 30% but you have the advantages of portability, and ability to work when engines are shut down.

In time you will notice that the lead plates become spongy and should the cell be used long enough the plates will finally crumble and break. You will notice that the more spongy the plates become the greater a charge they are capable of holding.

In fact, just before your battery goes to pieces its capacity is the greatest.

To make a commercially practical cell we would proceed thus:

The lead plates would be replaced by grids as shown in Fig. 693 or by grooved plates as in Fig. 694.

Litharge and sulphuric acid is mixed to a stiff paste and the grids or grooved plates plastered with the paste and stood up to dry. This makes a negative plate.

Using a paste of red lead and sulphuric acid the positive plates are formed in the same way.

The objection to a storage cell using these plates is that after very little use they go to pieces. The changing of the red lead to the brown oxide, and the changing of the litharge to spongy lead is accompanied by a swelling and shrinking of the material. This loosens up the pasted mass and it begins to fall out.

Most of the ingenuity of inventors has been concentrated on making plates which would hold the active materials firmly and continually.

Perhaps one of the best lead-lead (i. e. lead for both plates) is the Electric Storage Battery Company's Chloride Cell.

This cell is shown in Fig. 695. Its method of manufacture is interesting and is practically as follows:

The first thing is to get finely divided lead which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which upon cooling falls as a powder. This powder is dissolved in nitric acid and precipitated* as lead chloride on the addition of hydrochloric acid. This chloride washed and dried forms the basis of the material which afterwards becomes active in the negative plate. The lead chloride is mixed with zinc chloride, and melted in crucibles, then cast into

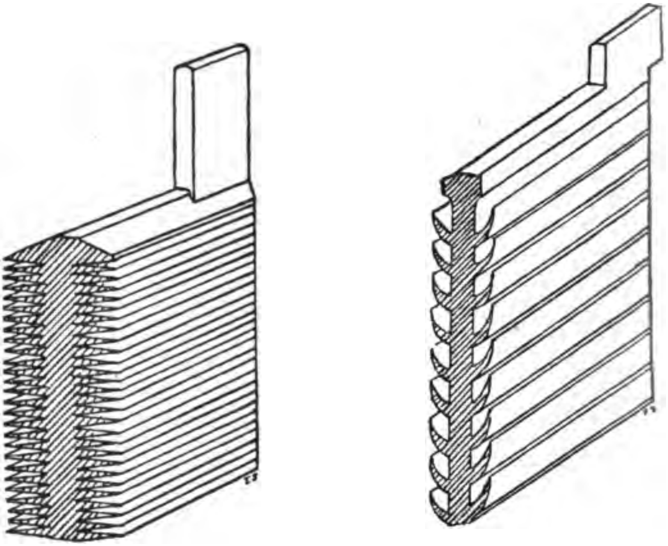


FIG. 694
GROOVED LEAD PLATES

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*Turned back to a solid.

small blocks or tablets about ¾ inch square and of the thickness of the negative plate, which according to the size of the battery varies from ¼ inch to $\frac{5}{16}$ inch. These tablets are then put in molds and held in place by pins, so that they clear each other 0.2 inch and are at the same distance from the edges of the mold. Molten lead is then forced into the mold under about seventy-five pounds pressure, completely filling the space between the tablets. The result is a solid lead grid holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. The assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

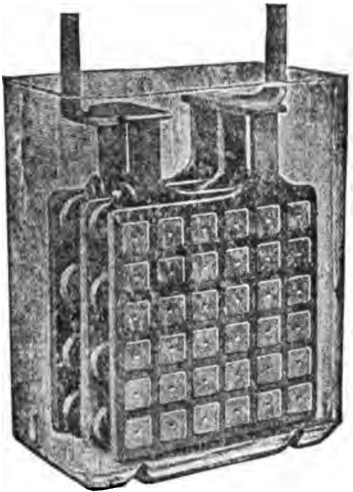

FIG. 695
CHLORIDE ACCUMULATOR

A later form of negative plate consists of a "pocketed" grid, the opening being filled with a litharge paste; this is then covered with perforated lead sheets, which are soldered to the grid. The positive plate is a firm grid, composed of lead alloyed with about 5% of antimony, about $\frac{7}{16}$ inch thick, with circular holes $\frac{25}{32}$ inch in diameter, staggered so that the nearest points are .2 inch apart. Corrugated lead ribbons $\frac{25}{32}$ inch wide are then rolled into close spirals of $\frac{25}{32}$ inch in diameter, which are forced into the circular holes of the plate. By electro-chemical action these spirals are formed into active material, the process requiring about thirty hours; at the same time the spirals expand so that they fit still more closely in the grids. This form of positive is known as the Manchester Plate.

In setting up the cells the plates are separated from each other by special cherry wood partitions, the perforations being connected by vertical grooves to facilitate the rising of the gases. Sometimes glass rods are used as separators.

There are ten sizes of cell, the smallest containing three plates 3 by 3 inches, and the largest having seventy-five plates 15½ by 30¾ inches, ranging in capacity from 5 to 12,000 ampere-hours, and in weight from 5½ to 5,800 lbs. The smaller sizes are provided with either rubber or glass jars, and the larger one with lead-lined tanks.

In the lead-lead cells the negative plates deteriorate in capacity, while the positive plates increase in capacity with continued use.

To even things up, the two end plates are made negative and they then alternate, thus giving one more negative plate per cell.

A lead-zinc cell is made by the United States Battery Co. It is shown in Fig. 696.

The positive plate is of perforated lead sheets riveted together with lead rivets, and formed by the slow process of charging and reversal as previously described. The negative element is a zinc amalgam which swells up when charged.

This amalgam lies on bottom of jar, while the lead element hangs over it.

The pressure given by these cells is a little higher than a lead-lead cell, and they weigh less for the same capacity. For signal work they are excellent, while for reserve power use, the lead-lead cell is preferred as being better under such severe conditions.

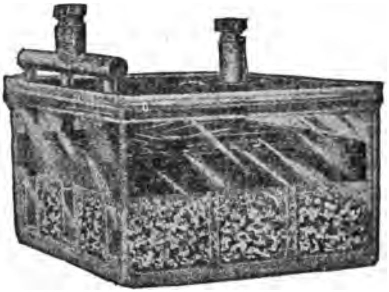

FIG. 696
LEAD-ZINC STORAGE BATTERY

The Edison Cell uses grids of nickel plated iron, the grids being filled with small nickel plated steel boxes which are perforated with very small holes.

The boxes in positive plate are filled with oxide of nickel and pulverized carbon, the negative boxes being filled with oxide of iron and pulverized carbon.

The carbon in each case is merely to render material a better conductor.

A 20% solution of caustic potash is used in a nickel plated steel vessel.

The advantage of this cell is its lightness and ability to stand the most reckless abuse. For railway work it is no better than any other cell and its price puts it out of consideration.

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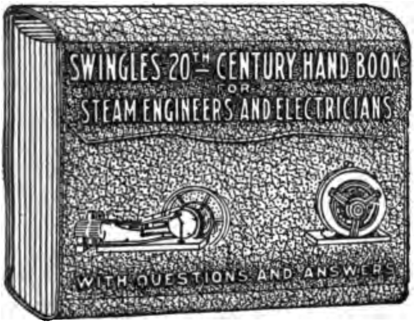
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